EXHIBIT 17

DECLARATION OF LEIF PETERSON IN SUPPORT OF HUAWEI'S OPPOSITION TO SAMSUNG'S MOTION TO PARTIALLY EXCLUDE AND STRIKE

Unpacking 3GPP standards[1]

Justus Baron

Northwestern University

Searle Center on Law, Regulation, and Economic Growth[2]

and

Kirti Gupta

Qualcomm Economics and Strategy

January 31, 2018

1. Introduction

Technology standards represent a set of rules and technologies adopted by a group of actors to ensure interoperability between products and services and to ensure that they meet specific industry requirements. The important role of technology standards is well understood in the Information and Communication Technology (ICT) industry, as they have been necessary for enabling mobile wireless communications, and the operation of the internet. In many parts of the ICT industry, technology standards have traditionally been defined cooperatively by governments or industry actors, working together to define technical features of new products or services, within formal standard setting organizations (SSOs).

SSOs are open and voluntary organizations using consensus-based processes to develop technological standards. Until recently, SSOs were little studied in the economic literature. Early research on technology standards was either theoretical or qualitative. Quantitative empirical research on technology standards is more recent, and is still limited to date by the scarcity of available data. Yet, in recent years, the functioning

[1] The Searle Center on Law, Regulation, and Economic Growth is making the database described in this paper available to academic researchers beginning in March 2018. All requests should be sent to searlecenter@law.northwestern.edu; or contact Justus.Baron@law.northwestern.edu for further information.

[2] Research at the Searle Center on Law, Regulation, and Economic Growth was financially supported by Qualcomm.

of SSOs and the nature of the conduct of participants in standard setting have been the focus of many public policy and scholarly discussions.

Many of these discussions have revolved around the role of Intellectual Property Rights (IPR) in standard setting. In particular, many SSOs have specific policies for the disclosure and licensing of IPR that are potentially essential to technology standards.[3] Several issues have been raised around the licensing of standard-essential patents (SEP), and proposals abound for changes in IPR policies of SSOs, valuation techniques for SEPs applied by the courts, as well as some proposed antitrust measures (FTC report (2011), Kuhn et al (2013)).

Nevertheless, there still is a lack of empirical research on how standards are developed, how different parties contribute to standard development, and how IPR and other policy instruments shape the incentives to contribute. To date no systematic and comprehensive database on the process of standard development and the functioning of SSOs is available for analyzing these issues empirically. The policy debate is therefore to a large extent based on economic theory and anecdotal evidence. In consequence, many proposed reforms have been criticized as being at odds with the complex institutional and technological realities of standard setting.

Existing empirical research has shed some light on standard setting processes at several SSOs (e.g. Leiponen, 2008; Simcoe, 2012). An important insight from this research is that there is a large heterogeneity in the rules and procedures of SSOs. Whereas some SSOs only allow individual participation, other SSOs have formal member organizations (most commonly companies). Each SSO has its own rules for the development and approval of technical specifications and standards. "One size fits all" approaches and policy recommendations may therefore not be appropriate for SSOs. Caution is warranted when drawing general conclusions from the empirical evidence, because economic effects of standardization processes and the incentives of the participating parties depend upon the complex institutional setting of SSOs, which differs from one organization to another.

We therefore believe that a deep dive in the institutional understanding of specific SSOs along with the relevant data collected from these SSOs may help in significantly advancing the literature on standard setting. Detailed studies focusing on selected important SSOs can reveal how and why firms participate in a specific standard setting process, how participating in this process affects the participating firms and whether participation in SSOs enables coordination and knowledge sharing. Careful empirical analysis of

[3] An IPR is deemed standard-essential if there is no method for implementing the technical standard that does not make use of the technology protected by the IPR. Even though different types of IPR may be declared to be potentially essential to the implementation of a standard, this is most common in the case of patents (patents declared as potentially essential to a standard are often referred to as Standard Essential Patents, or SEPs).

selected standardization processes can furthermore shed light on how technical contributions and the participation of specific actors determine the success of the resulting standards. Ultimately, such analyses can provide a solid basis for informed policy making for these important institutions.

The purpose of this paper is to describe a new database on the standard setting process for widely adopted and successful 3G and 4G wireless cellular standards defined by the Third Generation Partnership Project (3GPP), a consortium of seven SSOs. The dataset will be made available to academic researchers, and provides manifold opportunities for empirical research on standardization processes at 3GPP.[4] We selected 3GPP for our study, because several of the issues being raised with respect to standards and SEPs have been related to the wireless communications standards developed at this organization. The interest in 3GPP is unsurprising, given the enormous success enjoyed by the standards developed at 3GPP, and the enormous global economic impact they have generated. According to one estimate, the mobile value chain generated almost $3.3 trillion in revenue globally in 2014 and is directly responsible for 11 million jobs. This study identifies 3G and 4G wireless cellular standards defined by 3GPP as one of the major drivers of this economic impact (Bezerra et al., 2015).

This paper reflects a large data collection effort for unpacking the details of 3GPP standards from thousands of documents collected from the SSO's archives, such as meeting records, membership records, specifications, and technical contributions. Our goal is to further the understanding of the standard setting process, and share some preliminary insights from the data on 3GPP standards. We hope that this dataset will also serve as a template for the generation of other comprehensive datasets for studying and unpacking other SSOs. The collected data on 3GPP can be used in combination with two related databases: the Searle Center Database on Technology Standards and SSOs (Baron and Spulber, 2018), and a database of declared SEPs (Baron and Pohlmann, 2018). The three databases share a system of common identifiers, and are all available from the Searle Center for academic researchers.

The rest of this paper is organized as follows: Section 2 presents a survey of the literature on technology standards, with a focus on studies of single SSOs. A comprehensive analysis of a single SSO involves collecting data on various aspects of that SSO, requiring to first understand the institutional structure of that SSO. Therefore, Section 3 provides a historical overview of the formation of 3GPP and the 3G and 4G standards under discussion. Section 4 discusses the organization structure, rules, and procedures followed by 3GPP for the development of standards. After we assembled several data files via web-scraping and downloading, we collated the files, cleaned the data and standardized firm names across files

[4] The database will be distributed by the Searle Center on Law, Regulation and Economic Growth beginning in March 2018. For information regarding access to the database, consult http://www.law.northwestern.edu/research-faculty/searlecenter/innovationeconomics/data/ or contact searlecenter@law.northwestern.edu.

to generate a comprehensive data-set that we organize into five major categories: membership, attendance, contributions, change requests, and technical specifications. Section 5 presents and discusses the methodology of the data collection. Section 6 presents in detail the data on various aspects of 3GPP standard development. Section 7 concludes with some immediate insights and potential future research questions that this data-set may help answering.

2. Literature Review

While a substantial economic literature has studied technology standards, the specific institutions in which consensus standard setting takes place have only recently become a topic for economic analysis. Farrell and Simcoe (2012) and Bonatti and Rantakari (2016) analyze the efficiency of alternative decision rules in standard setting organizations (SSO). Lerner and Tirole (2006) and Chiao et al. (2007) describe the rules and membership composition of SSOs as endogenous to competition in the market for technologies, and in particular so-called forum shopping by the holders of patented technologies. Spulber (2016) analyzes decision making in SSOs, and predicts that the interplay between voting in SSOs and competition in the market results in the selection of efficient standards.

Empirical evidence to support these economic theories on standard development in SSOs is scarce. There are currently only very few studies comparing larger samples of SSOs with respect to their membership, procedures and output (e.g. Chiao et al., 2007; Baron et al., 2014).[5] Economists have therefore used practitioner surveys (Weiss and Sirbu, 1990; Blind and Thumm, 2004; Blind and Mangelsdorf, 2013) or companies' business communications (Aggarwal et al., 2011) to study SSO standardization. The most frequent approach is to use data on declared SEPs, which is available from SSO websites and can be matched with patent databases that are widely used in empirical economic research (e.g. Rysman and Simcoe (2008); Gupta and Snyder (2014)).[6] There is however still a lack of understanding how SSOs work, how standards are developed, and what the role and incentives of member companies and technology contributors are. A balanced and sound analysis of SSO policies and the role of SEPs requires a solid understanding of how SSOs function as economic institutions.

Detailed case studies of single organizations are an essential contribution to a better understanding of SSO standardization. A number of qualitative case studies first shed light on the economic incentives and

[5] see Baron and Spulber (2018) for a survey, discussion and a new database.
[6] see Baron and Pohlmann (2018) for a survey, methodological discussion and presentation of a new compilation of SEP declarations data.

strategic behavior of SSO members. Besen and Johnson (1986) and Farrell and Shapiro (1992) studied the dynamics of standard adoption, standards competition and vested interests of participating firms in the development of television standards by the Federal Communications Commission (FCC). Comparing two standardization projects at the Institute of Electrical and Electronics Engineers (IEEE) and at X3, Lehr (1996) studies the effect of SSO rules on cooperation among SSO members and firm preferences for a standardization venue. Bekkers (2001) studies three important standard setting projects at the European Telecommunication Standards Institute (ETSI), and documents the increasing importance of SEPs. DeLacey et al. (2006) compare the standard setting processes at the IEEE 802.11 working group and the development of DSL telephony standards and describe the important role of participating companies' vested interests and SSO rules. Blind (2011) analyzes the competition between ODF and OOXML document standards at the International Standards Organization (ISO).

A number of SSOs also provide procedural data on their websites that can be used for quantitative economic research. Two SSOs have been analyzed in a larger number of case studies: the Internet Engineering Task Force (IETF) and 3GPP. Using data on IETF meeting attendance, authorship of Requests for Changes (RFC), and working group chairmanships, Fleming and Waguespack (2009) investigate the effect of participation in standard setting by start-up companies on the chances of a public offering. Simcoe (2012) studies the effect of the composition of IETF working groups (i.e. the group working together on a RFC) on the time that it takes to process the RFC and on measures of quality and success of the resulting standard. Wen et al. (2014) study the effect of RFC releases on firms attending IETF meetings, distinguishing between RFCs contributed by firm employees and academics.

Using data on 3GPP work items and consortia related to 3GPP, Leiponen (2008) analyzes the effect of firm alliances on the likelihood that a firm's change requests are accepted. Using attendance data for 3GPP meetings from 1999 to 2009, Bekkers and Kang (2015) and Kang and Motohashi (2015) match the name of the individual attendees with inventors listed on SEPs to study the relationship between meeting attendance and patenting. Baron et al. (2015) use data on 3GPP meeting attendance and authorship of change requests to investigate the effect of participation in standardization on firm productivity.

In addition, more limited procedural data has been used in studies on a number of other SSOs. Rosenkopf et al. (2001) use attendance data for meetings at the Telecommunications Industry Association (TIA) to study the effect of joint meeting attendance on alliance formation. Also using TIA meeting attendance data, Gandal et al. (2004) study the relationship between patenting and standardization strategies in the modem industry. Cohen-Meidan (2007) uses data on membership in the IEEE 802.14 committee and a competing informal consortium to study the effect of competing standards on firm valuation. Wakke and Blind (2012) use the number of seats that a firm holds in the German national standards body DIN to measure the effect

of participation in standardization on a firm's productivity. Ranganathan and Rosenkopf (2014) collect data on firm votes on 242 ballots held at the International Committee for Information Technology Standards (INCITS) to analyze the effects of R&D and commercialization alliances on the likelihood that a firm supports another firm's proposal.[7]

Table 1: Overview of the reviewed quantitative case studies on SSOs[8]

SSO	Members	Meeting Attendance	Standards, Releases	Proposals, Votes	Collaboration on work items	Leadership; Chairmen
3GPP	BK2013 KM2015	BK2015 KM2015 BGS2015		L2008 BGS2015	L2008 BL2014	
IETF		FW2009 WFJ2014	S2012 WFJ2014	FW2009 S2012 WFJ2014	S2012	FW2009 S2012
TIA		RMG2001 GGG2004				
INCITS		RR2014		RR2014		
IEEE	CM2007					
DIN	WB2012					

The existing literature of quantitative SSO case studies is summarized in **Table 1**. It is apparent from this table that the different papers not only study different research questions, but also analyze different organizations and different variables. Meeting attendance is the only variable that has been studied for more than three different SSOs. Furthermore, many of the papers only study selected working groups at the different SSOs of interest, and all papers observe an SSO over a limited period of time. E.g. Leiponen (2008) and Bar and Leiponen (2014) use attendance data for 3GPP meetings held from 2000 to 2003, whereas Baron et al. (2015) analyze 3GPP attendance data for the period from 2004 to 2013. Finally, only

[7] They also use meeting attendance as control variable.

[8] BGS2015 = Baron, Gupta and Spulber (2015); BK2013 = Beckers and Kang, 2015; BL2014 = Bar and Leiponen (2014); CM2007 = Cohen-Meidan (2007); FW2009 = Fleming and Waguespack (2009); GGG2004 = Gandal, Gantman, and Genesove (2004); KM2015 = Kang and Motohashi (2015); L2008 = Leiponen (2008); RMG2001 = Rosenkopf, Metiu, and George (2001); RR2014 = Ranganathan and Rosenkopf (2014); S2012 = Simcoe (2012); WB2012 = Wakke and Blind (2012); WFJ2014 = Wen, Forman, and Jarvenpaa (2014)

the coded data used in Simcoe (2012) are currently available on the author's website, and all the different authors of the papers we surveyed coded their own data. This lack of a consistency between data sets being used makes it very difficult to compare the results from different studies.

The increasing number of quantitative case studies of SSOs yielded valuable insights on the standardization procedures at particular organizations, and also provided first evidence for more general economic research questions on standardization. Nevertheless, in order to make significant progress, it is necessary to create comprehensive and standardized databases covering all the important procedural data from a particular SSO, and to make this data widely available to other researchers. Studies using these data can be directly compared with each other, and their results can be easily replicated. This is the ambition of the database on 3GPP described in this paper. Ideally, our efforts on 3GPP set an example and a template for similar future projects on other SSOs.

Parts of the new database have been used and described in Gupta (2013) and Baron et al. (2015). The present article and database covers detailed procedural data from 3GPP, including membership, attendance, technical specifications, meeting dates, location and attendance, work items and contributions (including change requests) and contribution authorship and outcome. This comprehensive coverage of data from all institutional aspects of 3GPP is complemented by two different data-bases that include data related to 3GPP standards: (1) Data on membership and standard output of a large sample of SSOs, including 3GPP, presented in Baron and Spulber (2018); and (2) Data on declared SEPs, including patents declared to ETSI as being essential to 3GPP technical specifications, presented in Baron and Pohlmann (2018). These databases share a system of common identifiers and can easily be used in conjunction for research.

3. Historical overview

Using mobile devices for connecting with anyone anywhere around the world, browsing the internet, emailing, gaming, and mobile applications would not be possible without the high data rates enabled by core communications technology incorporated in the wireless cellular standards.[9]

Today, a majority of wireless systems in the world have adopted the so called third-generation (3G) and fourth-generation (4G) wireless cellular standards defined by 3GPP. 3GPP was formed in 1998 to develop

[9] Ericsson Mobility Report on the Pulse of the Networked Society, Telefonaktiebolaget LM Ericsson (June 2014), pg. 16 available at http://www.ericsson.com/res/docs/2014/ericsson-mobility-report-june-2014.pdf ("The modernization was primarily driven by the introduction of more efficient base stations that were capable of handling multi-standard technologies such as GSM/EDGE and WCDMA/HSPA. By contrast, modernization in other regions was primarily driven by the introduction of LTE.")

a common wireless cellular system for Europe, Asia and North America, representing a unified collection of seven global telecommunications SSOs and is primarily responsible for generating the standards endorsed by the member SSOs. This section provides a brief historical overview of the evolution of wireless cellular standards and the events that led to the formation of 3GPP.

The fundamental constraints on a mobile network are the allocated radio frequency spectrum and how efficiently this is utilized.[10] These constraints determine how many users and how much data can be transmitted through the network. There are other significant challenges, such as ensuring seamless communications continuity as users move rapidly, making communications power efficient without draining batteries, creating high-quality codecs for audio and video transmissions, *etc.* All of these fundamental advances occurred during the little told technology revolution that occurred in the realm of mobile technology standards over the last few decades. This section explores a brief history of the development of these standards, starting from the first-generation (1G) all the way to the current fourth-generation (4G) standards.

In 1983, Motorola's "brick phone" retailed for $3,995; this device is often cited as the introduction of the first-generation (1G) cellular system, which was based on analog signals transmitting voice between cell phones and radio antenna ("base stations"). The 1G systems did not enable multiple users to transmit signals simultaneously, and therefore, were expensive to scale. The phones required to transmit signals to far-away base stations were bulky and expensive. Additionally, the 1G systems were not designed to be compatible across countries, and global roaming was non-existent. Nevertheless, the popularity of cellular communications increased rapidly resulting in the need for common standards for cellular systems.

By the late 1980s, the telecommunications industry was drawn to developing a common set of 2G standards to improve the ability of consumers to access mobile networks. In Europe, the European Conference of Postal and Telecommunications Administrations (CEPT) started an effort to define a single digital 2G standard for mobile communications, establishing the GSM (Global System for Mobile Communication) in 1987, based on a new digital signal processing technology of the time called "time division multiple access" (TDMA). At around the same time, the United States witnessed a parallel effort for the creation of digital 2G standards based on a rival technology called "code division multiple access" (CDMA), which claimed to offer significant performance improvements over TDMA. In 1993, the American Cellular Telecommunications Industry Association (CTIA) issued the IS-95 (Interim Standard 95) based on CDMA. The 2G systems solved several important problems for wireless communications – mobile users could roam

[10] That is, the number of bits-per-second can be transmitted over the given amount of spectrum.

freely across the globe and still make voice calls, the efficiency of the networks increased, the size of the phones shrank, and voice quality improved significantly.

By the late 1990s, the industry was looking toward the next (third) generation of mobile systems, which would provide substantially increased data transfer rates, for going beyond voice communications and delivering data based services. In order to create globally applicable standards for 3G, 3GPP was formed as a unified collection of six global telecommunications SSOs known as organizational partners.[11] The efficient day-to-day running of 3GPP is supported by ETSI. 3GPP started working on specifications for 3G based on the established GSM core networks, though incorporating an evolution of the basic CDMA technology.[12] At the same time, another group in the US, with membership that partly overlapped with 3GPP, formed the 3rd Generation Partnership Project 2 (3GPP2), to develop rival global specifications for cdma2000, a 3G evolution of CDMA-based IS-95. This led to a highly public "3G standards war" between Ericsson and Qualcomm, with one firm proposing an evolution of GSM and another looking for an opportunity to develop a single, global CDMA based standard.[13] This dispute was resolved in around 1998, but the development of two standards – in 3GPP and in 3GPP2 – continued in parallel. The most widely used 3G standard today globally is WCDMA/UMTS developed in 3GPP, although the underlying technology that enabled the commercial use of CDMA has significant commonalities.

The formation of the 3G standards occurred over almost a decade through the development of numerous 3GPP releases. Each release encompasses important additions and improvements to the system (see Section 4.4).

The high data rates that 3G technologies enable gave birth to the user experience that changed the wireless communications paradigm -- mobile broadband. As soon as users could effectively browse the internet on their devices, the demand for data-rate grew exponentially. By 2008, it became clear that 3G networks would be overwhelmed by the need for faster and broader internet access, driven by a growing number of the mobile users and growth of bandwidth-intensive applications such as streaming media. Therefore, 3GPP

---

[11] These include: Japan's Association of Radio Industries and Businesses (ARIB), North America's Automatic Terminal Information Service (ATIS), China Communications Standards Association (CCSA), European Telecommunications Standards Institute (ETSI), Korea's Telecommunications Technology Association (TTA), and Japan's TTC (Telecommunications Technology Committee). In 2014, a newly formed body called the (Telecommunications Standards Development Society, India) TSDSI became the seventh member.
[12] The underlying 3G technology in 3GPP standards is called wideband CDMA (WCDMA), and the specifications are often referred to as Universal Mobile Telecommunication Systems (UMTS).
[13] See, http://www.ericssonhistory.com/changing-the-world/Big-bang/A-new-fight-/; Hjelm, Björn 2000 Standards and Intellectual Property Rights in the Age of Global Communication. http://arxiv.org/ftp/cs/papers/0109/0109105.pdf.

launched into the development of 4G technologies that enable high speed data for mobile devices in 2008, under the overall standard called the Long Term Evolution (LTE).

The main motivations for the development of 4G was the need for higher data-rates from consumers and desire for improved network efficiency and reduced network complexity from wireless network operators.[14] 4G LTE uses a different radio interface technology known as Orthogonal Frequency Division Multiple Access (OFDMA) in addition to several core network improvements to achieve these objectives. These technologies enabled higher spectral efficiency, higher peak data rates and increased flexibility in the frequency and bandwidth that can be leveraged by networks. Like 3G, the formation of the 4G standards occurred over several years and releases, with each release encompassing important feature additions and technological improvements.

4. The standard setting process

The purpose of 3GPP is to prepare, approve, enhance and maintain globally applicable technical specifications for 2G, 3G & 4G wireless devices.[15] 3GPP is based on voluntary participation by its individual member organizations, including firms and other entities. Decisions on technical specifications result from votes that are open to all members. Each quarter 3GPP consolidates all the technical specifications produced by all of its working groups. This consolidated information is provided to 3GPP's member SSOs as formal specifications.[16] The member SSOs then make them available to the wireless industry as a whole, at which point they are referred to as formal standards.

4.1 Organizational structure

These standards develop from a substantial effort and collaboration across hundreds of organizations with diverse interests and incentives. The complexity of the objectives necessitates a high level of organization, collaboration and efficiency within 3GPP. To help achieve this, 3GPP breaks desired objectives and features into smaller and smaller pieces until a manageable and targeted goal is outlined.[17] The technical objectives are then assigned to one of the four main technical specification groups (TSG) that are organized around broad areas of technical expertise.[18] These are: RAN (Radio-Access Network) which focuses on the

[14] http://www.3gpp.org/technologies/keywords-acronyms/98-lte.
[15] 3GPP Partnership Project; Working Procedures (2012) http://www.3gpp.org.
[16] We refer to '3GPP members' as the individual member organizations participating in the standard development process, as opposed to '3GPP member SSOs' refering to the seven SSOs that together constitute 3GPP
[17] See Appendix A for excerpt from 3GPP Working Procedures at: www.3gpp.org/specifications-groups/working-procedures.
[18] http://www.3gpp.org/specifications-groups/specifications-groups

UTRAN and E-UTRAN specifications of the radio-physical layer interface, SA (Service and System Aspects) which focuses on the service requirements and the overall architecture of the 3GPPP system, CT (Core Network and Terminals) which focuses on the core network and terminal parts of 3GPP including the terminal layer 3 protocols and GERAN (GSM/EDGE Radio Access Network) which focuses on 2G technology including GSM radio technology, GPRS and EDGE.

Each TSG further breaks their assignments into specific goals known as features. Each feature is a new or substantially enhanced functionality which represents added value to the existing system according to the majority of 3GPP members.[19] A feature most commonly reflects an improved service to the end-customer or increased revenue generation potential to the supplier. The features can be broken down into building blocks that can in turn be organized into a number of work tasks which lead to the production of new technical specifications or augment/improve existing specifications. The specific work tasks or work-items are then assigned by the TSG to one of the Working Groups (WGs) that roll-up to it (see **Figure**). The majority of the technical work that results in the development of technical standards occurs here in the working groups. 3GPP currently has 13 working groups working on 3G and 4G standards. Each WG meets 6-8 times per year, with hundreds of representatives from member firms around the world, and therefore the meeting locations rotate across continents.

The output of the WGs is then presented at the TSG plenary meeting for information, discussion and approval. These meetings result in the final specifications provided by 3GPP to member SSOs who subsequently publish them as formal standards. Each TSG meets two times per year at plenary meetings.

The TSGs themselves are further governed by the Project Coordination Group (PCG), the highest decision making body responsible for overall management of 3GPP technical work. The PCG ensures that the formal specifications are produced in a timely manner as required by the market place, ratifies election results (for the chair position of different groups within 3GPP), and allocates the resources committed to 3GPP. The PCG also handles any appeals from the member organizations on procedural or technical matters. The PCG meets twice per year.

[19] See 3GPP TR 21.900 for definition.

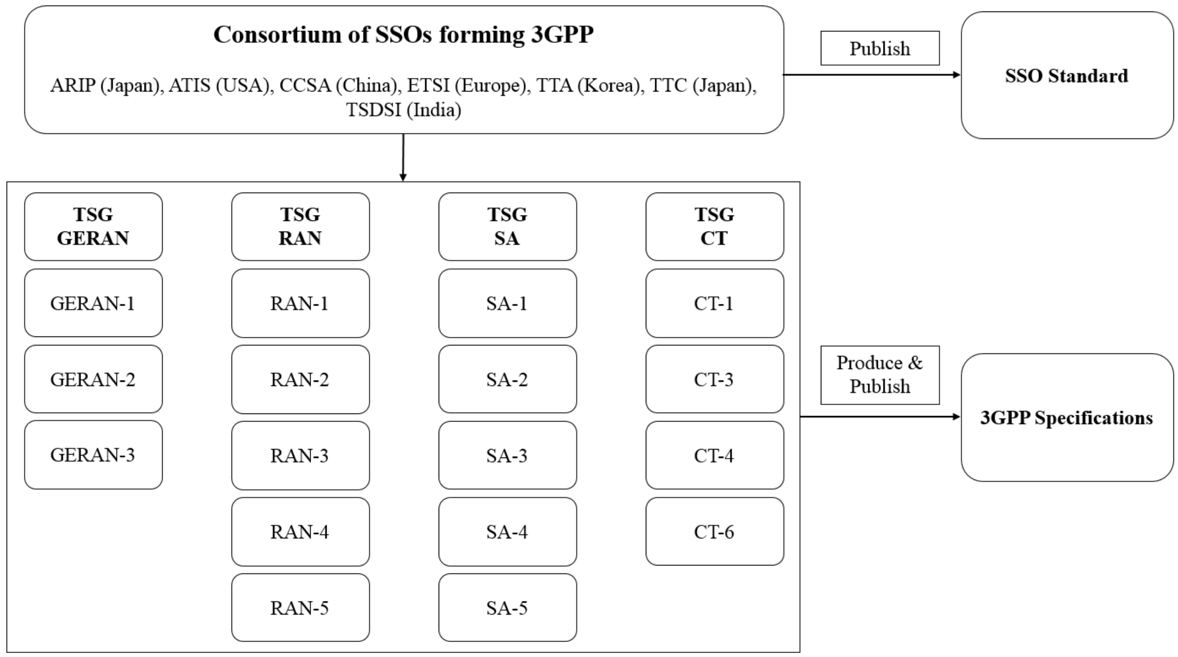

Figure 1: Organizational structure of 3GPP

4.2 Chairmanships and the voting process

As in most organizations, leadership plays an important role in 3GPP. Two of the most important leadership positions are the chairman and vice-chairman of a given working group (WG) or technical specification group (TSG). The chairman helps ensure an objective and valid approach in determining what gets reviewed in a given meeting and what the final decision will be.

The chairman and his vice-chairmen both are elected officials. TSGs have a chairman and up to three vice-chairmen. WGs have a chairman and up to two vice-chairmen. All chairmen and vice chairmen are elected by participants of the group concerned using a secret ballot for a two year term. Each individual member entity gets one vote. TSG chairmen further need approval from the Project Coordination Group (PCG), which ensures that leadership is balanced and power is shared across regional and organizational lines. TSG elections occur in odd-numbered years, during the spring plenary meetings. The timing of WG elections vary to some extent but follow a similar term-length. According to 3GPP, anyone can be elected to chairman or vice-chairman, who is known and respected by the group and who can commit a great deal of time and

energy to the job.[20] This usually requires official approval from the individual's organization to ensure sufficient time and resources can be allocated to these responsibilities.

There are specific requirements that individual participants must meet in order to obtain the right to vote in elections of 3GPP leadership. Specifically, an individual participant must be represented at two meetings, without missing three in a row. These voting rights also allow organizations to participate in the decision-making process related to specific technical contributions or discussion topics which occur at the working group and TSG levels. As such they are highly valued by members.

4.3 Creation of the technical standards

The technical work leading to the technical specifications that become the wireless cellular standards is largely performed at the level of the various 3GPP working groups. A new feature (proposing a new or enhanced functionality) can be initiated by anyone, however, it must have the support of at least four individual member organizations which agree to contribute actively to the development of the necessary specifications for inclusion into the work program of 3GPP. The smaller tasks that the feature is broken down into make their way into the working groups as specific work items. Each work item in turn can result in one or more technical specifications. The proposal of a new feature, therefore, is the first step towards the formation of the future technical specifications that become standards.

Once the proposed feature and the corresponding work item(s) are approved, technical work begins in the working groups. For work on any technical specification, member organizations submit technical documents called contributions for addressing various technical issues and proposing solutions for them. These contributions are then reviewed and discussed amongst all the members in the working group meetings. 3GPP follows a consensus building or a majority voting governing rule for selecting between competing proposed solutions.[21]

A typical working group meeting is conducted as follows. The contributions are submitted and made publicly available prior to each meeting. Interested meeting delegates representing the member organizations typically review the contributions prior to the meeting, and come prepared with their comments and feedback. During the working group meeting, the elected chair announces the agenda and schedules the respective contributions for discussion. The contribution is then presented by the author(s) in front of all the attendees. Per the governing rules of consensus building, the chair provides equal opportunity to each member organization to object to any contribution. Therefore any attendee can raise his/her hand

[20] ftp://www.3gpp.org/webExtensions/trainingMaterials/3GPP_TheTrainingCourse_Module_13_electionsVoting.pps

[21] See, 3GPP working procedures, available at: http://www.3gpp.org/specifications-groups/working-procedures

in a meeting objecting to a contribution's potential inclusion in the technical specification(s). If any such objection is made, the author(s) of the contribution has to work with the objector(s), and resubmit a revised contribution. Such a process can take several iterations and revisions. If no consensus can be achieved, the chair must resort to voting. The governing rules of 3GPP stipulate that at least 71% of the member organizations must agree for a contribution to be accepted/approved for inclusion in the technical specification. After a series of such meetings and iterations, a technical specification is formed.

Figure 2 provides a visual aid to help in the understanding of the 3GPP standard-setting process which has been described here.

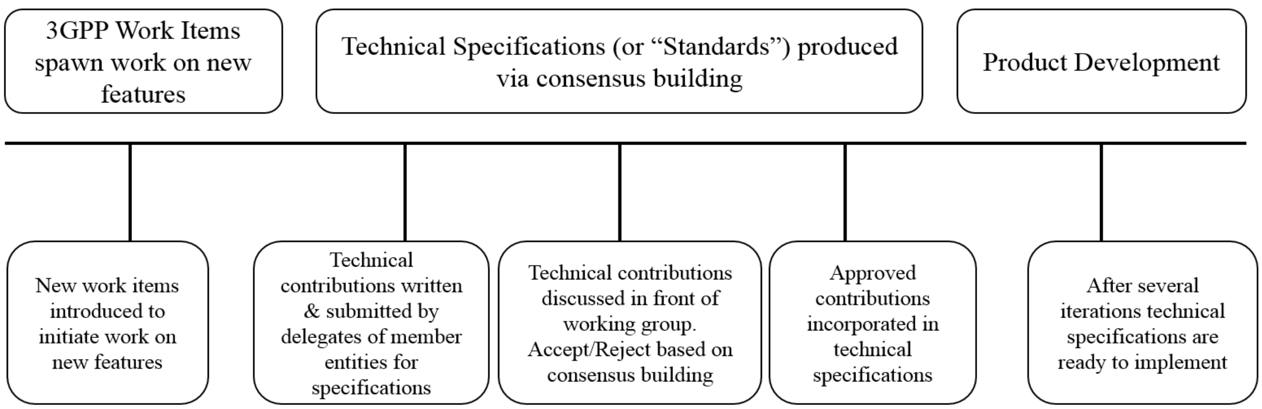

Figure 2: The Standard Setting Process

Often, hundreds of technical contributions have been submitted and discussed towards the formation of single technical specification, and the entire process takes several months. Technical specifications are live and dynamic documents that are defined and modified over long periods of time.[22] After 80% of the development work on a technical specification is completed, it can be approved by the TSG. Hereafter, any technical change can only be accomplished by submitting a special type of contribution called a change request. An approved specification may still undergo significant changes. The TSG can freeze specifications for a specific release of the standard when the functionality of that release is stable, and 99% of the development work for a technical specification is deemed to be complete.[23] When the technical specifications are in a stable format, typically at the point when they are approved by the TSG and have the first version number, product development work can begin and downstream manufacturers can start implementing the specifications. As a step of formality, the 3GPP technical specifications are also formally approved and published as endorsed standards by the member SSOs at this point.

[22] http://www.3gpp.org/specifications/specifications
[23] The date on which all work is stopped on a given release by the TSG is known as the freeze date

4.4 Releases and features

Throughout the process of building technical specifications, 3GPP members actively participate in a consistent and objective process. The contributions that are at the center of this process represent the most fundamental piece of how work at 3GPP is accomplished. Individual contributions are usually focused on one part of a given feature and because of that, it is sometimes difficult to understand the impact of these efforts and any one document on the consumer and wireless industry. When looked at in the aggregate, however, the specifications and standards which directly result from these contributions can more clearly show the impact of these efforts. Each new release of technical specifications and standards can be directly tied to new and improved features which can be credited with important developments in the wireless industry.

3G and 4G standards are made up of a number of these features which combine to create substantial leaps in the technological evolution of wireless communications. These evolutionary steps in the technology come from the combination of research and development efforts from hundreds of firms investing billions of dollars in R&D (Gupta, 2015). The development of these standards is broken up into various releases. Each release is made up of hundreds of technical specifications that have been built by thousands of contributions made by hundreds of firms. **Figure** shows each 3G and 4G release along with the number of associated change requests submitted and the associated features/enhancements.

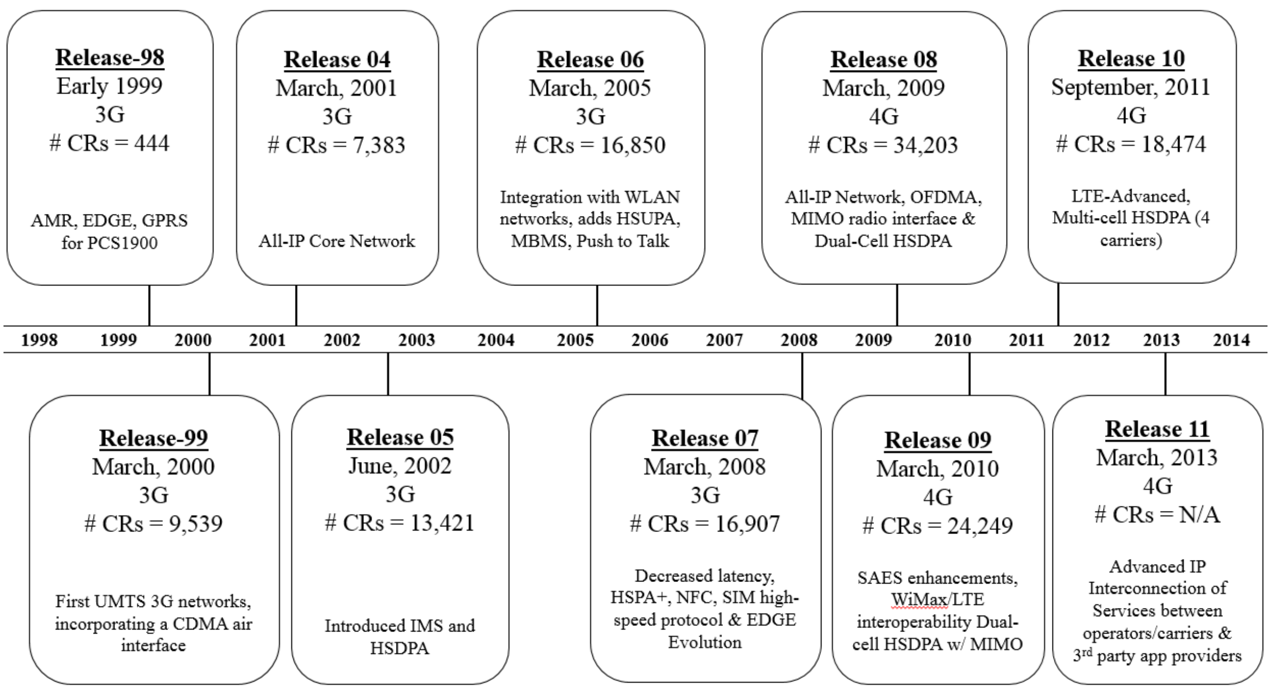

Figure 3: 3GPP Releases by Freeze Date, Number of CRs and Features (Rel-98 – Rel-11)

5. Methodology

In order to understand the dynamics of membership, participation, the scope and the level of effort that go into developing standards based on these complex cellular technologies, as well as the dynamics of creation of the technical specifications that then become standards, we have created a comprehensive dataset covering the various institutional aspects of 3GPP standard setting. This dataset covers six important aspects of 3GPP standard setting: (1) membership, (2) meeting attendance, (3) technical contributions, (4) change requests, (5) technical specifications, and (6) work-items (or features).

The data collection effort undertaken for this paper involves scraping, downloading, collating, and then standardizing and merging thousands of individual documents representing hundreds-of-thousands of unique records and millions of data-points from the 3GPP website and its associated FTP server. 3GPP is founded on the ideas of transparency and openness.[24] To ensure that these goals are achieved, a large majority of the standard-setting process is recorded in documents and TSG/WG meeting reports available on 3GPP's FTP server. These documents include lists of all 3GPP member entities, the publishing of WG meeting reports that record the participants, their member entity affiliation, as well as the contributions and CRs submitted for each meeting along with their authors, revisions, and outcomes. These meeting reports were aggregated across hundreds of meetings and multiple WGs and TSGs to develop the comprehensive data-set presented here.

The challenges associated with collecting, standardizing and publishing a clean and concise data-set covering 3GPP standards are many. The 3GPP FTP server and website are available to anyone who is interested, but are not necessarily intuitive without prior institutional knowledge of the organization. The typical users of the FTP server are standards engineers who are involved in the process. These individuals are usually concerned about the details of individual contributions or meetings but not necessarily with the high-level or aggregated information that is likely to be of interest to researchers. The most fundamental challenge is understanding what information is available and what the information represents in relation to the standard-setting effort, and categorizing this information appropriately. For example, there are many types of technical contributions (or "t-docs"), and we categorize them in broad categories of interest to researchers. Another example is normalizing the outcomes of the discussions of technical contributions from the meetings into major categories, e.g.: whether they were accepted, rejected, noted, etc.

One of the other major significant challenges is the inconsistency in the format of reports between different working groups. Instead of one template for meeting reports and contribution lists, working groups are given control over how they document and record their specific information. In general, WGs capture the

---

[24] http://www.3gpp.org/specifications-groups/working-procedures

same overall information, however the format varies substantially. This means that the same data-point may be titled differently (e.g. contribution status vs. contribution decision) and that the values within the reports may change (e.g. not seen vs. not treated or agreed vs. approved). In addition the order of the variables changes frequently across working groups.[25] These variations in the order and names of variables prevents the use of any automated system to merge the thousands of files which are collected from the 3GPP website. The format of meeting reports and of contribution lists also frequently changes over time within the same working group. Even within the same working group the terminology and format of reports changes approximately once every 1-2 years.[26] These seemingly minor variations, when aggregated across thousands of files and millions of data-points, necessitate substantial effort and caution. We researched each identified difference across meeting reports to ensure that slight variations do not actually represent any meaningful differences. Meeting minutes were used for validation purposes. These reports contain detailed information about the conversations that occur in a WG meeting about contributions. This information allows us to understand exactly what the data represent within the standard-setting context.[27]

In addition to the meeting minutes, each dataset requires an in-depth study of the published 3GPP working procedures and the methods used by working groups to record the information. In many cases this required a detailed understanding of the process through which technical specifications are developed and a review of the individual meeting reports.[28]

6. An overview of the 3GPP data

The next section provides an in-depth explanation of the variables available in each of the datasets, including the definitions according to 3GPP. In many cases the raw data has been normalized or involved significant post-processing. When this occurs, we explain the process for doing so and clearly explain any limitations to the data-set.[29] Lastly we provide some preliminary analysis of the data showing the breakdown by WG and examining the trend in the data-sets over time.

We have organized the data to reflect six fundamental aspects of standards development at 3GPP.

---

[25] e.g. the contribution type field (change request, discussion document, etc.) may be the third variable in one meeting and change to the 10th variable in the next meeting

[26] The frequency of these changes is not formulaic and some working groups change seemingly every meeting while others were more consistent in their format

[27] Frequently we also consulted with standards engineers involved with the process to understand these differences

[28] Interested readers should review documents available at http://www.3gpp.org/specifications-groups/working-procedures; http://www.3gpp.org/about-3gpp/about-3gpp; http://www.3gpp.org/technologies/tutorials-tools;

.[29] We also include the original raw data in the data-sets to allow other researchers to develop their own taxonomies if they so desire.

Table **2** provides a summary of each of the six aspects of the data and includes links to the source data as well as information on the number of records, the time-frame available and other important notes.

Table 2: Summary of 3GPP Data

Category	Source	No. of Records	No. of Parent Entities	Time Frame	Notes
Membership	2013 & 2014 Member List, 2000 Member List, 2011 Member List	1,429	489	2000-2014	This is the only data-point that is based on point-in-time data
Attendance	example - 3GPP RAN-1 Working Group - List of Meetings	93,327	492	2005-2014	
Change Requests	http://www.3gpp.org/specifications/change-requests	152,854	287	1994-2012[30]	
Contributions	ftp://ftp.3gpp.org/	301,316	330	2005-2013	Only available for RAN, SA & CT (no GERAN)
Technical Specifications	http://www.3gpp.org/specifications/specifications	9,547	N/A	1994-2013	
Work Items	http://www.3gpp.org/ftp/Information/WI_Sheet/	3,060	335	1994-2013[31]	

[30] 2012 is not a complete year data available through 9.2012; 1994 is also not a complete year it starts in 11.1994
[31] This date range is approximate for the work items as the date the work item was created is not available. We do know that we have capture every work-item available on 3GPP's FTP server.

The collected data has been compiled into nine different tables, which can be joined using common identifiers. Figure 4 provides an overview over the database. In addition, company names and standard (technical specification) designations can be joined with the Searle Center Database (Baron and Spulber, 2018). Each box in Figure 4 represents a different table in the database, and each row in each box represents a different variable. In Appendix A, we provide a detailed code book with further information on the data in each of these tables.

3GPP_attendance
meeting_id
company-name-normalized
parent-company-financial-level
attended
individualrole

3GPP_meetings
meeting_id
meeting_title
workinggroup_id
tsg_id
city
meetingstartdate
meetingenddate

3GPP_contributions
tdoc_number
meeting_id
document_type
revised_document_type
raw_document_type
raw_document_title
decision

3GPP_contribution_authorship
tdoc_number
firm-level-normalized
parent-company-financial-level
raw_author

3GPP_changerequests
cr_ID
meeting_id_1stlevel
tdoc_nr_1stlevel
tdoc_nr_2ndlevel
spec_id
release
cr_title
cr_type_definition
submission_date
work_group_id
tsg_id
meeting_id_2ndlevel
decision_2nd_level
decision_cleaned_2ndlevel
work_item

3GPP_change-request_authorship
cr_id
raw_company_name
company_name
source_level

3GPP_workitems
work-item_id
tdoc_number
work-item-title
new-spec-created
affected-specs
tsg-id

3GPP_supporting_entities
work_item_id
raw_company
company-name
parent-company-name
tsg-id

3GPP_specs_workitems
spec
release
work_item_id

Figure 4: Structure of the 3GPP database

6.1 Membership and attendance

To become a member of 3GPP, one must first become a member of one of the seven member SSOs. All 3GPP member SSOs offer membership on a voluntary basis, often with a small fee. We developed the list of entities that were members of 3GPP by normalizing the names across the various membership lists and

rolling up the subsidiaries to their parent organizations (2000-2014).[32] 3GPP lists the current list of members on its website (at www.3gpp.org/membership), but does not list or publish historic membership records. We were able to obtain the membership lists for the years 2000, 2011, 2013 and 2014.

In total there were 1,447 membership records across the four identified membership lists. Table 3 lists the number of unique parent entities that were identified in each of the uncovered membership lists. The union between these four lists results in 489 parent entities that have been identified as members.

Table 3: Number of Parent Entities per Membership List

Year of List	Parent Entities
2000	256
2011	280
2013	298
2014	279

The 2014 list of members included some additional details about the organizations listed as members (in the following referred to as firms), such as: (i) the SSO(s) to which the firm is a member of and (ii) the location of the headquarter of the firm. Firms can be members of multiple SSOs and the average firm is associated with 1.2 SSOs ($\sigma = 0.6$).The vast majority of members are affiliated with ETSI (82%, see **Table 4**). Members were headquartered in 37 different countries in 2014. In 2014, the United States represents the country with the highest proportion of members (n=50, 18%) followed by France (n=28, 10%), the United Kingdom (n=28, 10%), Germany (n=25, 9%) and Japan (n=21, 8%).[33]

[32] For example VODAFONE AirTouch Plc, VODAFONE, VODAFONE España, VODAFONE Group Plc, Vodafone Ireland Plc, VODAFONE LTD, etc. were all listed as members on the membership lists.

[33] As of January 2017, the enlarged 3GPP (also including TSDSI as new organizational member) has 526 individual member organizations. The country with the largest number of headquartered individual 3GPP members in 2017 is China (n=70), followed by the United States (n=68).

Table 4: Number of Individual Members in the seven 3GPP SSOs per 2014 membership list

SDO	Parent Entities	Geographical focus
ARIB	24	Japan
ATIS	28	United States
CCSA	23	China
ETSI	230	Europe/RoW
TSDSI	Had not joined yet	India
TTA	12	Rep. of Korea
TTC	8	Japan

Not all members attend all of the working group meetings. Significant insights can be gained from which firms are choosing to participate in various meetings (such as, based on the functionality of the working groups, or meeting locations etc.), and the amount of resources a firm is devoting (such as, the number of meetings attended, or the number of employees attending etc.). Therefore, we create an attendance record of all the working group meetings within the various TSGs in the years 2005-2014.[34] Each working group publishes a meeting report for every meeting, listing the participating individuals and their affiliations with a 3GPP member. The attendee dataset is created by aggregating the meeting reports from 825 working group meetings. The names of firms are then cleaned, standardized and rolled up to their parent firm. These records represent a total of 3,452,040 man hours spent in 3GPP meetings.[35] This statistic highlights the substantial amount of time and effort that has been devoted by 3GPP participants to the development of 3G and 4G standards.

Table 5 shows the breakdown of total man-hours spent in meetings by the TSG and WG responsible for the meeting. It also shows the number of firms who have ever attended a meeting at the TSG and WG level. Over half of all man-hours have been devoted to meetings held by the RAN TSG during this time period.

[34] Data is available beginning in 2005. Prior to 2005 there is a significant amount of missing data within the attendance lists. Most importantly, less than 1/5 of all attendance entries contain the affiliation to which the individual associated.

[35] This calculation assumes an 8 hour work-day for all days for which a meeting occurred. For example, if there was a 5 day meeting it would be assumed that each participant spent 40 hours in the meeting.

Table 5: Number of Firms Attending and Number of Hours Spent in Meetings by TSG & WG

TSG	WG	No. of firms	Meeting Hours		
			Total	% of 3GPP	% of TSG
CT		176	549,448	16%	
	CT1	134	233,824	7%	43%
	CT3	95	116,712	3%	21%
	CT4	116	160,544	5%	29%
	CT6	79	38,368	1%	7%
GERAN		92	92,992	3%	
	GERAN1	83	42,448	1%	46%
	GERAN2	72	50,544	1%	54%
RAN		310	1,898,688	55%	
	RAN1	205	627,600	18%	33%
	RAN2	191	510,800	15%	27%
	RAN3	156	213,216	6%	11%
	RAN4	211	385,544	11%	20%
	RAN5	157	161,528	5%	9%
SA		316	861,240	25%	
	SA1	185	163,632	5%	19%
	SA2	205	456,392	13%	53%
	SA3	123	106,232	3%	12%
	SA4	111	134,984	4%	16%
Joint Meetings		95	49,672	1%	

Additional insights into the development of 3GPP standards can be gained by investigating when attendance occurred amongst the various working groups. To this aim information on the start and end-date of meetings was also collected. **Table 6** shows the amount of attendance over time based on the start-date of the meeting. Attendance overall steadily rose until 2011, at which point it began to decline.

Table 6: Total Meeting Hours by Year

Start Year	No. of Firms	Meeting Hours	% of Total Meeting Hours
2005	195	247,296	7%
2006	211	329,928	10%
2007	213	378,032	11%
2008	216	390,288	11%
2009	204	429,088	12%
2010	234	450,552	13%
2011	219	453,192	13%
2012	228	374,536	11%
2013	226	296,488	9%
2014	174	102,640	3%

Figure 5 shows the breakdown of attendance by the TSG responsible for the meeting.[36] The RAN WG meetings have enjoyed the highest amount of participation based on man-hours attended in each year from 2005-2013. This likely demonstrates the importance of the technology areas covered by the RAN WGs to the wireless cellular standards.

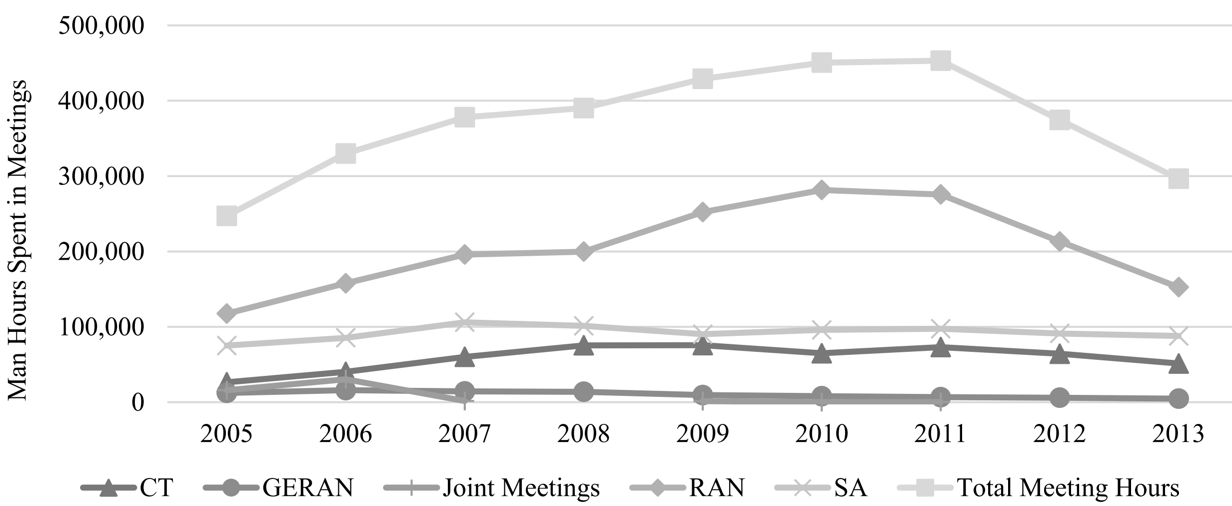

Figure 5: Meeting Hours by TSG over Time

[36] Data on when individual member firms first and last attended 3GPP meetings is also available.

6.2 Work-Items

The technological scale and complexity of 3GPP standards necessitate a division of the work into smaller and smaller pieces. These projects make the work more manageable and help by outlining clear goals in terms of what work needs to get done. These targets are commonly known as Features, and represent new or substantially enhanced functionality which represents added value to the existing system.[37] New features are proposed by submitting a document known as a work-item description (WID) at a TSG plenary meeting for approval.[38] In order for a work-item to be proposed, accepted, developed, and certified it must have the support of at least four individual member entities.[39] Once the work-item is proposed and accepted, the supporting Individual Members are expected to contribute to and progress the new work-item throughout the drafting phases. If at any point new contributions to a work-item cease for an extended period of time the TSG has the opportunity to close the feature.

The complete list of active work-items make up the 3GPP work-plan, which provides details of cooperation between all TSGs and WGs and helps direct behavior towards achieving common targets. This allows for a number of features to be worked on in congruence while minimizing any duplication of effort. Thus, in aggregate, work-items represent a fundamental outline of the features and work being conducted within the standard and represent an important data-point in understanding the workings of 3GPP.

3GPP maintains a directory of work-item descriptions, which is available on its FTP server.[40] This database includes work-item descriptions for both current work-items, as well as each closed or completed work-item. The dataset regarding work-items was collected directly from these submitted work-item descriptions (WID).

A number of different variables within a WID are useful for characterizing and categorizing a work-item and were collected as part of the work-item data-set. WIDs contain information on the supporting companies of a given work-item. While a minimum of four supporting companies are required to propose a work-item, in many cases the number of entities is significantly higher (μ=9.6, σ=7.3).

WIDs also contain a list of specifications that a given work-item is expected to impact. There are two manners in which a work-item can impact a specification. A proposed work-item can result in a new

[37] http://www.3gpp.org/specifications/work-plan/65-work-items
[38] http://www.3gpp.org/specifications/work-plan/66-features-and-study-items
[39] http://www.3gpp.org/ftp/Information/Working_Procedures/3GPP_WP.pdf
[40] http://www.mmnt.net/db/0/27/ftp.3gpp.org/Information/WI_Sheet/

specification(s) that previously did not exist and/or it can impact a number of already developed specifications. Each WID lists the specifications that were created or that are impacted. Information on the working group responsible for the work-item is also provided and can be used to identify the technology area to which the work-item relates (i.e. GERAN, RAN, SA or CT). Thus the final database contains information on the work-item document number, the supporting companies, the new and impacted specifications and the working group which is responsible.

A total of 3,060 work-items were available on 3GPP's FTP server. Data was collected for each of these, with each row in the data-set representing a unique work-item. In cases where a WID has been revised the most recent version of the document was used to collect the data.[41] Much of the data required significant post-processing and normalization. For example, the entity names of the supporting companies on each WID were normalized and aggregated to the parent entity. In addition, the list of impacted specification numbers needed normalization to ensure consistency in format.[42] It is also important to note that not all data-points were available for all of the work-item descriptions. 2,493 (81%) of the work-items contain information on the precise specifications which they relate to and impact. Similarly, 2,465 (81%) listed the supporting companies for the work-item. A larger percentage had information on the TSG to which the work-item was assigned (2845, 93%).

The dataset on work-items allows us to answer a number of interesting questions. In total, 335 companies were listed at least once as a supporting company for a work-item. Among those listed as a supporting company, the average parent entity was listed on 81.3 (σ=229.4) unique work-items with a range from 1-1,815. The distribution among member companies is highly positively skewed with the top 10 companies making up 58% of all supporting companies. This further supports the assertion that a few highly active firms are largely responsible for the technical development of the standards. We also looked at the breakdown of work-items by the responsible TSG. The results of this analysis further support the importance of the RAN TSG which is responsible for a disproportionately large amount of the work-items (see **Table 7**).

---

[41] Data was collected as of July, 2015

[42] For example, sometimes companies listed an impacted spec number as 1.01 and sometimes as 01.01. Specification numbers were also sometimes too general. For example, a company might state that all specifications within the 34.xxx category of specifications may be impacted. This means that all specifications that start with "34." are impacted. In these cases we normalized the spec numbers so that all affected specifications were explicitly identified (e.g. 34.001; 34.002; 34.034, etc.)

Table 7: Work-Items by Responsible Technical Specification Group

TSG	No. of Work Items	% of All Work Items
CT	500	18%
GERAN	240	8%
RAN	1139	40%
SA	966	34%

6.3 Contributions

Contributions represent a fundamental data-point in the understanding of the standards setting process and the development of technical specifications. Within 3GPP, contributions are available for each working group, with each group generally following the same process to enter and record contribution-related information. To begin this process, the chairman of a given working group decides on the contributions that will be reviewed and discussed at a given meeting. These documents are aggregated into a list, which is then made available to meeting registrants prior to the meeting start date. These contribution lists are known as temporary document lists or t-doc lists, i.e., a unique t-doc number is associated with each contribution. After the meeting, the t-doc list is made publicly available and is augmented with additional information such as the type of contribution and the decision reached during the meeting.

To develop the dataset of contributions we downloaded and merged all the available t-doc lists for every meeting held by the RAN, SA & CT TSGs from 2005-2013. GERAN contributions are not available and therefore excluded from this dataset.

The source data is made publicly available on 3GPP's FTP server and organized by TSG and work-group with each meeting consistently having a folder which contains the relevant data.[43] Within each meeting we downloaded the "meeting report" file and collected the published t-doc list if it was available. If no t-doc list was available the meeting report document was consulted to determine if a t-doc list was available in the appendix. We were able to locate data on contributions from 96% of working group meetings from RAN, SA & CT for the years from 2005-2013.[44]

The format for these lists was not consistent with each other and frequently did not include all of the same fields across groups/meetings. To address this, we reviewed the t-doc lists for consistent fields that were seen as potentially useful for answering research questions around SSOs. For each contribution we captured

[43] e.g. ftp://ftp.3gpp.org/tsg_ran/ & ftp://ftp.3gpp.org/tsg_ran/WG1_RL1/
[44] A complete list of the meetings is available with the database and the WG meetings that are missing is completed. Prior to 2005 the data is very sparse and inconsistent both within and across working groups.

the author/source, the type of contribution, the decision made in the meeting, the meeting to which the document was submitted and the meeting start date.

We collected a total of 301,316 contributions from the t-doc lists. There were 396,028 authorships, since one contribution may have multiple authors ($\mu = 1.4$, $\sigma = 1.2$). However not all contributions contained data on the source/author of the document. A total of 268,523 (89%) of all contributions that were collected contained information on the firm responsible for the contribution.[45]

We provide the contribution data broken down by the date of the meeting to which it was submitted (see **Table 8**). Contribution submissions reached their highest level in 2009 the same year that the first 4G LTE release was being published.

Table 8: Number of Contributions and Contributing Firms based on Date Submitted

Meeting Start Date	No. Contributions	% Contributions	No. of Contributing Firms
2005	13,991	5%	129
2006	23,546	8%	152
2007	33,336	11%	167
2008	46,325	16%	153
2009	50,519	17%	173
2010	45,698	16%	175
2011	41,068	14%	181
2012	37,081	13%	173

Lastly, **Figure 6** shows the trend of contributions over time (based on meeting start date) by the TSG responsible for the meeting to which the contribution was submitted.

[45] 282,958 have some sort of value listed in the source/author field from the t-doc lists. However, 14,435 only list a 3GPP working group or TSG as the author/source rather than the actual affiliation(s) from which it was created.

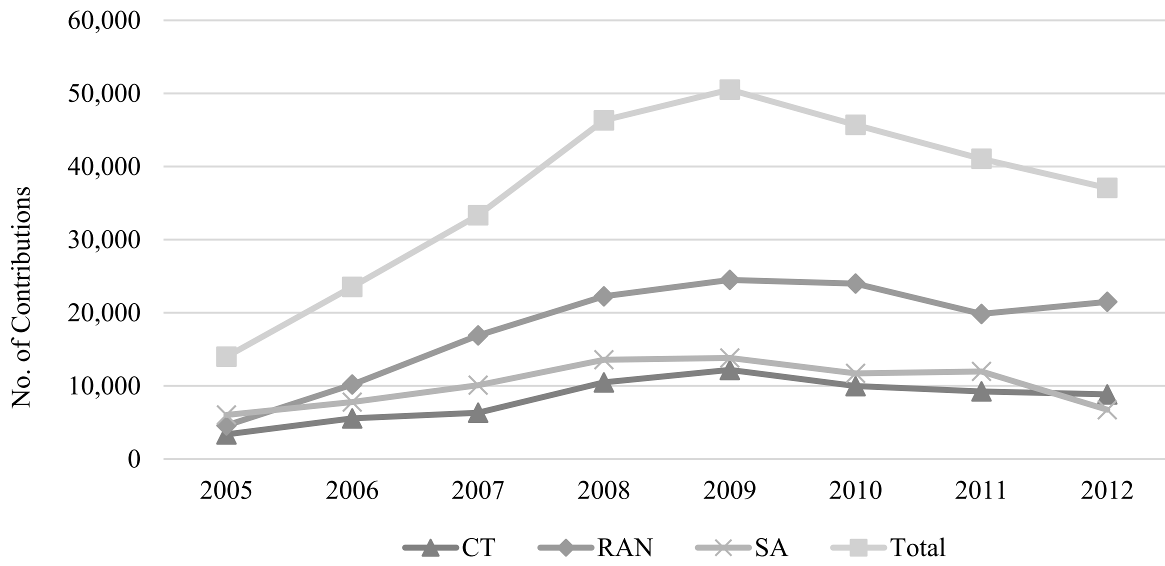

Figure 6: Contributions by Date Submitted and TSG

Additional insights into the 3GPP standard setting process can be gathered by combining the data-sets described above. **Figure 7** shows the distribution of contributions amongst all attending firms. A total of 492 firms attended a 3GPP meeting. The distribution of contributions submitted is highly skewed, with a few firms submitting the vast majority of contributions. For example, the top 2% of the firms (9 firms) are responsible for submitting 60% of all contributions. Furthermore, approximately one-third of all participating firms (33%, 161) have not submitted a single contribution to 3GPP. These results highlight the fact that a few highly active firms are largely responsible for the technical development of 3GPP.

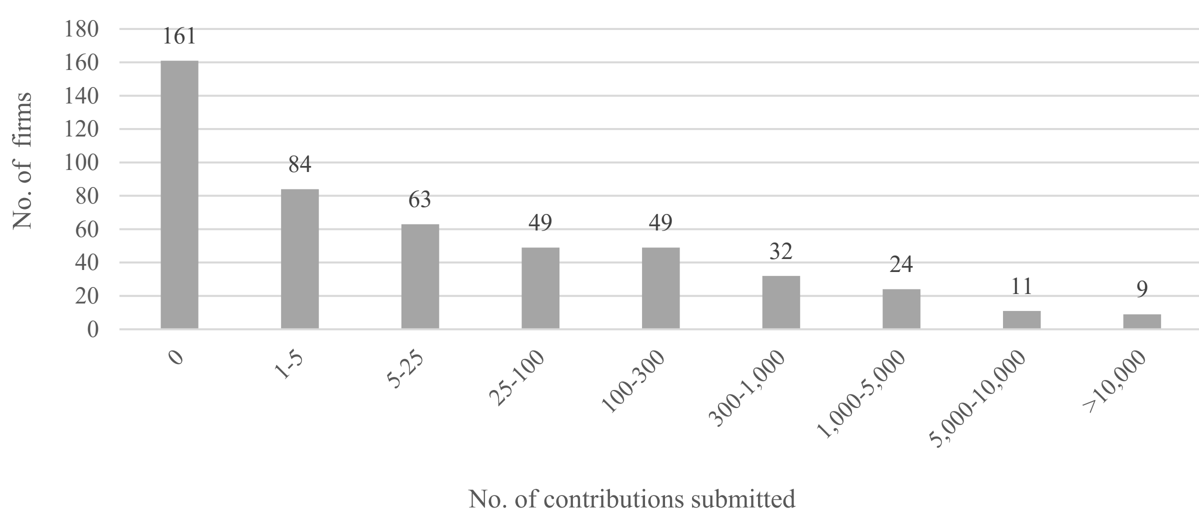

Figure 7: Distribution of Contributions by Participating Firms

We also collected information about the number of firms contributing to each TSG and WG. **Table 9** includes the number of entities participating and the proportion of all attending firms who have submitted at least one contribution. The last column includes the proportion of all contributions that are authored by the Top 10 most active contributing firms. These statistics provide information on the degree of skew in the distribution of contribution authorship for various working group and TSGs.[46] Similar to the distribution for 3GPP overall, results consistently show that a large percentage of participating firms do not contribute (12-53% depending on working group and TSG) and that the top 10 contributing firms are always responsible for a large proportion of all contributions submitted (47%-79%). This finding confirms that a minority of firms are largely responsible for the technical development of the standard.

Table 9: Number of Contributing and Participating Firms per TSG & WG

TSG	WG	No. of Participating Firms	No. of Contributing Firms	% of Participating Firms Who Contribute	% of Contributions Submitted by Top 10 Firms
CT		176	154	88%	67%
	CT1	134	109	81%	68%
	CT3	95	64	67%	75%
	CT4	116	78	67%	79%
	CT6	79	65	82%	65%
RAN		310	187	60%	65%
	RAN1	205	105	51%	64%
	RAN2	191	104	54%	70%
	RAN3	156	93	60%	74%
	RAN4	211	125	59%	72%
	RAN5	157	74	47%	73%
SA		316	220	70%	58%
	SA1	185	132	71%	47%
	SA2	205	115	56%	65%
	SA3	123	83	67%	71%
	SA4	111	104	94%	70%

In regards to the type of contribution, we categorized contributions into six categories based on the type data available in the t-doc lists. Those categories are change requests, discussion documents, technical

[46] Only working groups that had available data on both contributions and participation were included in **Table 9**.

reports, technical proposals/studies, liaisons and withdrawn documents.[47] **Table 10** provides the breakdown of contributions by type and also includes the formal definition of each category according to 3GPP. The raw data on contribution type required some cleaning and the exact mapping of the raw data is available for review.[48] There were a total of 546 different contribution type values which were mapped to the categories defined below. We have also included the original contribution type data as it existed in the t-doc list. This information will allow researchers to determine their own taxonomy for contribution type if they desire.

Table 10: Contribution Type Definition and Counts

Type of Contribution	Definition	No. of Contributions	% of Contributions
Change Request	Specifies in precise detail changes which are proposed to the specification	146,237	49%
Discussion Document	A document that proposes a topic to be discussed by the work group	41,787	14%
Liaison	A formal request by a working group for information or detail from another 3GPP working group or external standards organization that is relevant to the work being done by the requesting work group	26,385	9%
Technical Report/Proposal/Study	These include feasibility studies and technical studies and reports which are typically submitted to working groups for informational purposes	66,526	22%
Void/Withdrawn	A contribution that was submitted but withdrawn prior to the start of the meeting and was therefore not discussed and no decision made	2,462	1%
Unknown	Blank contribution type (missing data)	17,919	6%

[47] In many cases, t-docs also include documents which may not be technical in nature but do represent the contribution of effort to the 3GPP organization (e.g. nominations for 3GPP positions, voting documentation, meeting minutes, agendas, documented procedures etc.). All of these documents are included in this dataset and categorized as discussion documents.

[48] Certain contribution groups could be debated as to which of the four categories below they best fit into. For that reason, we call out a few that are of note; namely, "PCRs" (pseudo change requests) are counted as a change requests (CR) and a documented "Decision" is counted as a discussion paper. All other contributions cleanly mapped to one of the four categories in **Table 10**.

In addition to the type of contribution, we collected information on the decision reached during the meeting for each of the contributions. Similar to the data on change requests, the decisions field required significant clean-up and post-processing to normalize the data into meaningful categories. There were 28,084 unique values, which were recorded in the decision field within the contribution lists. We mapped these values to one of the six categories in **Table 11**.[49] This table provides the breakdown of contributions by the decision reached in the meeting to which it was submitted. Table 11 provides a definition for each decision category based on information in the 3GPP working procedures.[50]

Table 11: Contribution Decision Definitions and Counts

Decision	Definition	No. Contributions	% Contributions
Approved	positive consensus at WG level	81,527	27%
Not Treated	Contribution was submitted to the meeting but not reviewed usually due to time constraints	44,610	15%
Noted	not presented for decision at the present time, therefore just taken as information	63,045	21%
Rejected or Withdrawn	Negative consensus or withdrawn by author prior to a decision being reached	21,260	7%
To Be Revised	Comments from standards participants have highlighted the need for changes to the contribution in order for it to be approved	73,601	24%
No Decision Available	Blank (missing data)	17,273	6%

6.4 Change Requests

Change requests (CR) are a unique type of contribution. Firms submit CRs to propose additions, edits, or modifications to an *existing* technical specification. The document specifies in precise detail the changes which are proposed to the specification. Every change request presented to a TSG plenary meeting is

[49] The exact mapping used is available for viewing in the 3GPP database
[50] http://www.3gpp.org/specifications-groups/working-procedures

recorded in the CR database maintained by 3GPP.[51] This database lists the status of each CR, and, if approved, indicates which version of the specification was subsequently created. The CR database contains records about every change request related to specifications from GSM phase 1 onwards and contains CRs that were submitted between November, 1994 and September, 2012.

In total there are 152,854 change request records available. The source data comes directly from the 3GPP CR database, but two important variables required significant post-processing and clean-up. First, the CR status or decision field had to be grouped into useful and meaningful categories. This data represents the decision that was made by the TSG about a CR. Although only 9 decision categories exist according to 3GPP, there were 412 unique values that were included in the decision field within the 3GPP database. These values were mapped to one of the categories you see in **Table 12.** The definition of each category is based on information available at the 3GPP website and the number of CR records within each category is also provided.[52]

Similar to the data on attendance, the information on the original authorship or "CR-source" of the document required significant cleaning. The names of submitting firms are cleaned, standardized, and rolled up to their parent firm. There are 1,544 unique firm names listed as authors in the CR database. We mapped these firm names to 287 parent firms.

[51] http://www.3gpp.org/specifications/change-requests
[52] http://www.3gpp.org/specifications/change-requests

Table 12: Change Request Decisions and Counts

Decision	No. of Records	% of Records	Use/Definition
Not Treated	7,022/589	5%	Not yet seen, no decision reached
Agreed	80,201	52%	Positive consensus at TSG level (final decision)
Rejected/ Not Agreed	3,405/216	2%	Negative consensus
revised	42,640	28%	Modified to new revision of same CR
postponed	5,048	3%	Decision deferred to later date, normally indicates WG will re-examine
tech endorsed	404	0.3%	Consensus at WG level that CR is technically correct, but there may be other solutions (which may be presented in parallel to TSG)
withdrawn	8,524	6%	Either never produced, or retracted by author prior to TSG decision
merged	72	0.1%	Involves combining CRs with similar or overlapping content; most unlikely to be used
noted	4728	3%	Not presented for decision, therefore just taken as information

We also captured CR information based on the date they were originally submitted to a working group. This provides insight on the date that the idea was originally presented to 3GPP. **Figure 8** shows the trend in CRs over time, and shows that CR submissions peaked in 2009.

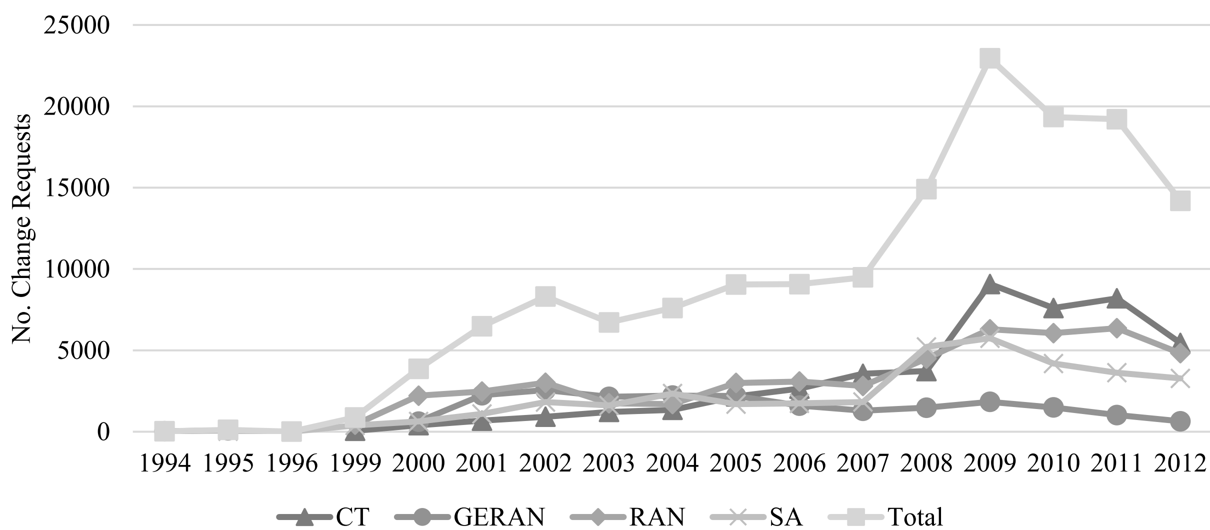

Figure 8: Change Requests by Submission Date and TSG

CRs also vary in terms of the type of change the document is associated with. According to 3GPP there are five types of CRs.[53] **Table 13** provides the definition of each category according to 3GPP and the number of CRs in each category. More than half of all CRs are classified as essential corrections.

Table 13: Type of Change Request Definitions and Counts

Type of CR	Definition of CR Type	No. of CRs	% of CRs
Essential correction	Used: 1.) to correct an error in the specification (i.e. a clear instruction in the specification which leads to incorrect operation of the system); or 2.) to correct an ambiguity in the specification which could lead to different implementations which cannot inter-operate; or 3.) to remedy the incorrect implementation of a previously approved CR; or 4.) to correct a misalignment between the specifications (stage 1, stage 2 & stage 3) for a feature or service when not introducing a new function or functional change.	88,050	58%
Correction to earlier Release	Used to reflect functionally equivalent changes made to an earlier Release of the same Specification.	26,950	18%
Addition of feature	The new feature is to be added to the Release; the reference is not to the Specification itself. This will normally correspond to an identified Work Item. This category shall not be used for a frozen Release, except for alignment CRs as described below.	24,396	16%
Functional modification	Any functional modification shall correspond to an identified Work Item. However backward compatibility shall be ensured when the issue has an impact on the UE	5,829	4%
blank	No CR type available (missing data)	5,573	4%
Editorial modification	Editorial modifications shall have no impact on an implementation. An editorial modification CR to a frozen Release shall not be permitted.	2,056	1%

Several fields are also available for categorizing CRs by the technologies they relate to. Most importantly, we provide data matching CRs to the technical specifications they are associated with. Specifications are very precise descriptions of the technologies that make up wireless cellular standards. There are 1,231 specification numbers to which at least one CR is associated ($\mu = 124$, $\sigma = 448$).

Table 14 shows the top ten specifications in terms of number of associated CRs. Included in the table is the specification number, the number of associated CR records and the definition of the specification

[53] Detailed explanations and definitions of the change request type is available here http://www.3gpp.org/ftp/specs/archive/21_series/21.900/

according to 3GPP. Change Requests can also be categorized based on the work-item that it is associated with. The work-item is a less precise description of the technology a CR is related to relative to a specification.

Table 14: Top 10 Technical Specifications by Number of Change Requests Submitted

Specification No.	No. of CRs	Specification Description
24.229	2,362	IP multimedia call control protocol based on Session Initiation Protocol (SIP) and Session Description Protocol (SDP); Stage 3
51.010-1	2,264	Mobile Station (MS) conformance specification; Part 1: Conformance specification
23.401	2,204	General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access
25.331	2,072	Radio Resource Control (RRC); Protocol specification
34.123-1	2,070	User Equipment (UE) conformance specification; Part 1: Protocol conformance specification
44.06	2,022	General Packet Radio Service (GPRS); Mobile Station (MS) - Base Station System (BSS) interface; Radio Link Control / Medium Access Control (RLC/MAC) protocol
23.06	1,947	General Packet Radio Service (GPRS); Service description; Stage 2
24.301	1,928	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3
24.008	1,927	Mobile radio interface Layer 3 specification; Core network protocols; Stage 3
25.433	1,856	UTRAN Iub interface Node B Application Part (NBAP) signaling

At a higher level, information on the release to which a CR is related is also available. Each release encompasses a large number of technical specifications that together comprise a new set of features or work-items. 3GPP Release 8 has the highest number of associated change requests. This release represented the introduction of 4G/LTE.

6.5 Technical Specifications

Technical specifications represent the ultimate output of the work completed in 3GPP. These technical specifications are published by 3GPP after each standards release and used by downstream manufacturers to provide guidance on the development of 3G and 4G devices. Similar to the CR data-set, 3GPP maintains their own database on specifications.[54] Each specification is identified by a 4 or 5 digit number (e.g. 01.01 or 23.001) that categorizes specifications into meaningful technical categories.[55] The specification database includes information regarding if the specification is currently active or if it has been withdrawn in subsequent releases of the standards. It also includes the release that the particular version of the specification is related to.[56] **Figure 9** shows the breakdown of active and withdrawn specifications by the release to which it is associated.

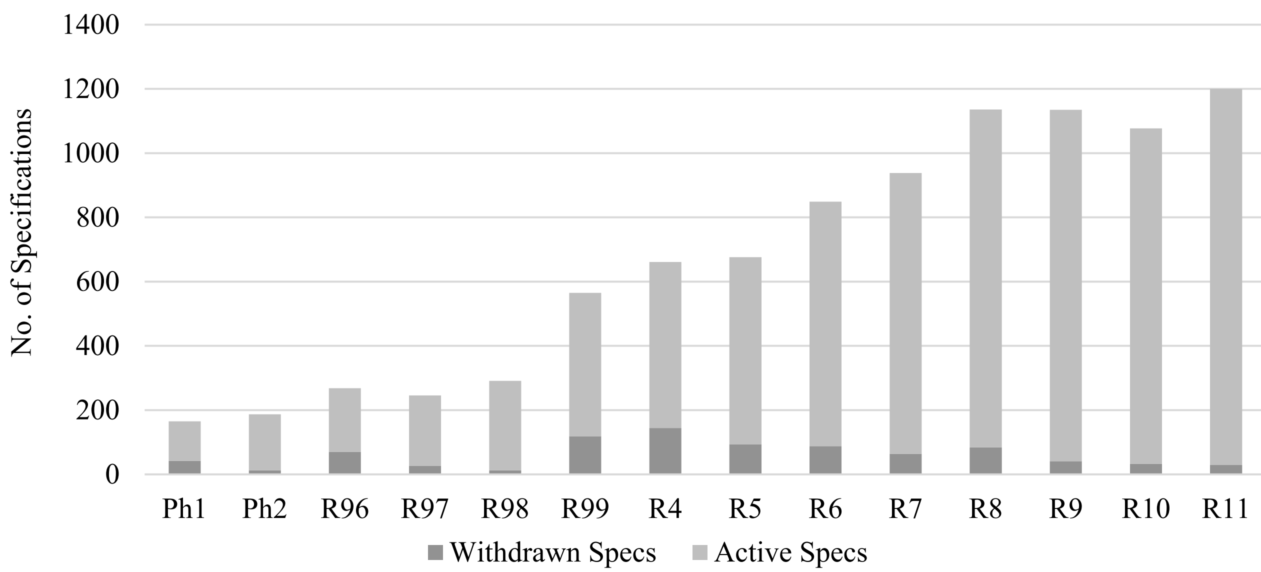

Figure 9: Number of Specifications Associated with each Release

[54] http://www.3gpp.org/specifications/specifications
[55] For interested readers, please refer to the specification numbering page on 3GPP website to understand the different categories and types of specifications http://www.3gpp.org/specifications/specification-numbering
[56] One specification may have multiple versions related to different releases and therefore the same spec number may be listed in multiple releases

According to 3GPP there are two types of specifications; (1) technical specifications (TS) (2) technical reports (TR). The difference between a technical specification and technical report is that a TS is typically a technical standard whereas a TR is typically for informational purposes. This information is included in the specification database. **Table 15** presents the breakdown of specifications by specification type and status (i.e. active vs. withdrawn)

Table 15: Active and Withdrawn Specifications by Type

Type	Active	Withdrawn	Total
TR	1255	344	1599
TS	7429	518	7947

The database also has information on responsible working group and technical specification group. **Table 16** includes the number of active specifications that are associated with each working group.[57] These numbers are then aggregated across working groups to provide the number of specifications by TSG. SA is the TSG with the most specifications associated with it, followed by CT and RAN.

[57] In some cases the specification is not associated with a specific working group but instead lists the TSG plenary as the responsible party; we identify these cases separately in **Error! Reference source not found.**

Table 16: Active Specifications by Working Group and TSG

TSG	Working Group	Total
CT		2460
	CT1	655
	CT3	343
	CT4	1000
	CT6	219
	CT Plenary	243
GERAN		798
	GERAN1	398
	GERAN2	375
	GERAN Plenary	25
RAN		1337
	RAN1	188
	RAN2	233
	RAN3	417
	RAN4	321
	RAN5	156
	RAN Plenary	22
SA		4050
	SA1	862
	SA2	359
	SA3	479
	SA4	975
	SA5	1312
	SA Plenary	63

Lastly the specification database also contains information that links work item descriptions to technical specifications. All WIDs were collected from each technical specification found on the 3GPP website up until March 2016. We then link the supporting companies from the WID supporting entity database to the technical specifications based off of the WID. There are a total of 11,336 data points with 1,399 technical specifications and 1,563 WIDs. There are an average or 9 WIDs associated with each TS and conversely, an average of 7 technical specifications associated with each WID.

7. Discussion / research outlook

We briefly discuss some of the concerns related to the wireless communications standards developed by 3GPP standards, and how a deep-dive into the institutional knowledge of the standards development process and analyzing the underlying data can help.

7.1 SEPs

An aspect of standardization that has motivated an important and growing body of economic analysis is the fact that some standards can only be implemented using patented technologies. Data on SEPs, discussed in detail in a related article (Baron and Pohlmann, 2018), can be related to technical contributions, which are covered by the data described in this paper. Technical contributions are the unique technical solutions to problems the technical challenges that an SSO faces. Many of these solutions are patented, as an outcome of the R&D that led to these potential solutions. While competing technical contributions are discussed at the standards working meetings at 3GPP, and some are chosen based on technical merit, in a parallel process individual firms have the obligation to determine the list of patents that are potentially essential to the forming standards, and declare this list of "potential SEPs" to their member SSO (most commonly the declarations are made to ETSI). There is a strong correlation between who contributes and who declares SEPs. A comprehensive SEP database for standards developed by 3GPP is maintained by ETSI, and included in the database discussed by Baron and Pohlmann (2018).

One major concern is the risk of potential "patent hold-up" of standard implementers by the holders of such SEPs after the standards have been set (Farrell et al, 2007; Bekkers and West, 2009; Bekkers et al., 2011). While the definition of "patent hold-up" has evolved, one of the primary definitions involves "deceptive conduct" by a patent holder, which induces an SSO to select his patented technology. Detailed data on the 3GPP standard setting process and the technical contributions made by 3GPP members allows examining the empirical relevance of the hold-up hypothesis. The fact that the technologies included in the standard are determined based on consensus and/or majority voting amongst members after a transparent process of selection across alternatives casts doubt on the prevalence of "deception".

As another example, some observers have cautioned that 3G telecom standards are subject to "too many SEPs", potentially giving rise to a "royalty stack".[58] While testing the royalty stacking theory is a study in

[58] See Lemley (2002), "Time and time again, we have seen this sort of royalty-stacking problem arise. One great example is 3G telecom in Europe. The standard-setting organization (SSO) put out a call for essential patents, asking which they must license to make the 3G wireless protocol work and the price at which the patent owners would

and of itself, it is impossible to determine what constitutes "too many SEPs" without analyzing the scope, size, and the number of technical solutions that form the entire standard. Using detailed data on technical contributions to 3GPP, one can compare the ratio of patents to technical contributions across standards, which provides a more meaningful basis of analysis than simple counts of patents.

Others have tried to analyze the relationship between SEP declarations and participation in standards, claiming that "participants systematically influence the content of the standard in the direction of their own patented technologies" (Bekkers et al., 2011). However, without analyzing the relationship between *technical contributions made by participants* and their SEP declarations, claims about the relationship between participation and patenting are incomplete and unlikely to provide insights into the behavior of firms. Our data on 3GPP can be used in conjunction with a new database on SEPs (see Baron and Pohlmann, 2018). In particular, in this paper we describe how to identify work items, CRs and other contributions related to a specific technical specification. We also identify the authors of these contributions, and the supporting entities of work items. Baron and Pohlmann (2018) describe how to match technical specifications to declared SEPs. Using the two datasets together thus makes it possible to compare the set of contributors and the set of companies declaring SEPs for a specific technical specification.

Specific discussions related to the valuation of SEPs can also be informed based on the deep-dive data from 3GPP.

One of the suggestions related to the valuation of SEPs is "ex-ante valuation" (e.g. Farrell et al., 2007; Lerner and Tirole, 2015). The idea is that the licensing fee for SEPs should only be based on the determination of their value prior to the standard being set, to eliminate the possibility of SEPs capturing any value attributed to standardization itself. Our dataset helps shed light on the practicality of "ex-ante" valuation of technologies that are incorporated into standards. In particular, the data provides information on several iterations and revisions that are made over the years to technical specifications. This evidence suggests that the standards world is not divided neatly into an ex-ante and ex-post universe.

As another example, in order to understand the value of SEPs, it is first important to understand the scale and size of the standard setting process for the technologies under study. Another suggestion has been to apply numeric proportionality for valuation of SEPs. In other words, if an SEP owner owns 10 out of a list of 100 total declared SEPs, they should be attributed 10% of the total value of the SEP portfolio of that technology (Chapatte, 2006). This is a method deployed widely by patent pools, which have been promoted by some as a promising licensing instrument for SEPs (Shapiro, 2001). Our data reveals that some firms

---

license their rights. 3G telecom received affirmative responses totaling over 6000 essential patents and the cumulative royalty rate turned out to be 130%. This is not a formula for a successful product."

are spending far more time and effort on development of some technical areas than others, making it clear that all technologies are unlikely to be equal in their value, consistent with the economic literature on patent valuation demonstrating the value of patents in a portfolio is highly skewed (Hall et al., 2005).

7.2 Efficiency of standardization processes

An important and growing body of economic literature analyzes the efficiency of standard setting processes. There are two main aspects to this analysis. First, an important stream of research investigates whether standardization results in the selection of the "right" technology standard, and whether inefficient or outdated technology standards are replaced or become entrenched as a result of technological "lock-in". More recently, economists have focused on the time and resources required for standardization participants to come to an agreement. While it is impossible to directly measure the efficiency of standardization processes at 3GPP, the data provides manifold opportunities to test specific predictions of the theoretical literature on standard setting.

The question whether standardization results in the selection of the most efficient technology standard is subject to a long-standing controversy in economic research. In particular, David (1985) and the subsequent literature on path-dependency in technological innovation argue that selection of an inefficient standard is difficult to reverse, and has durable effects on subsequent technological innovation. Spulber (2008) has pointed out that theories of technological lock-in of inefficient technology standards tend to assume that there is no explicit coordination among firms on the selection of a standard. The processes of SSOs are designed to facilitate coordination on the selection of a standard. The database on 3GPP standardization processes provides many opportunities to study the emergence of consensus on a standard from initial submission of a work item, which evolve through change requests subject to competitive votes, up to the adoption of a new technical specification. Data on the authorship of the different work items, contributions and change requests made in this process can indicate the different firms and other entities participating in this coordination process, and the gradual emergence of a consensual standard.

A recent theoretical literature on the efficiency of standard selection explicitly takes voting in SSOs into account. Spulber (2016) finds that there is an inverse relationship between market power of firms in an industry and the voting power of this industry in SSOs. Market power and voting power thus have balancing effects, resulting in the selection of efficient standards. Bonatti and Rantakari (2016) study the implications of different voting rules, and suggest that there is a trade-off between inducing selection of the efficient standards and providing incentives to exercise efforts in standard development. The rich data on technical contributions, contribution authorship and decision outcomes at 3GPP can be used to test these predictions

empirically, and to investigate the relationship between decision outcome on a firm's contributions and the firm's market power, or its level of efforts in standard development.

Another concern has been that larger incumbent firms participating in the standards may potentially control the standard setting process to push their proprietary solutions into the standard. This concern has been supported by observing the number of technical contributions made by different participants (Bekkers and Kang, 2015). However, the fact that some firms are contributing more to technology standards than others may only reflect coordination in the industry allowing firms to focus on their comparative advantages, which is indeed what SSOs are designed to facilitate. Detailed data on submitted technical proposals by different firms and their final outcomes, i.e., the rate of acceptance or rejection of technical proposals by differently situated firms, as can be obtained from our data-set, may help in shedding light on the fairness of the standard setting process.

In addition to the concerns about the selection of efficient standards, economists have worried about the speed and cost at which consensus on standards emerges. In particular, Farrell and Simcoe (2011) and Simcoe (2012) caution that firms' vested interests in specific standard designs, and in particular standards including their proprietary technology, may induce costly "wars of attrition" and inefficiently delay the emergence of a consensus. The 3GPP database allows directly testing whether the speed at which work items proceed to adoption has declined, or is negatively correlated to the existence of IPR. Furthermore, the database can shed light whether technical specifications resulting from more lengthy standardization processes are of higher quality, have a higher expected survival time, or achieve higher adoption rates. Measures of the quality, survival or adoption of standard documents can be produced from the Searle Center Database (Baron and Spulber, 2018).

7.3 Participation in standard setting

Another area of empirical research on SSOs investigates the incentives for firms to participate in costly standardization processes. Several recent empirical contributions shed light on how firms may benefit from participating in SSOs (Fleming and Waguespack, 2009; Baron et al., 2015). Nevertheless, how different forms of participation affect a firm's performance is still a subject for future investigation. In particular, while Fleming and Waguespack (2009) and Baron et al. (2015) find evidence for learning benefits from attending SSO meetings, there is no evidence on how successfully influencing the outcome of standardization processes affects a firm's profits or productivity.

Another significant area for future research is the analysis of interactions between firms through SSOs. Aggarwal et al. (2011) find that by coordinating standard development with other firms, standardization participants are able to mitigate the risks inherent to technological innovation. Delcamp and Leiponen (2014) find that firms participating in the same standardization consortia increasingly build upon each other's R&D, as measured by patent citations. In addition to further investigating these effects, 3GPP data can be used to analyze how joint participation in standardization affects the interaction between firms more broadly. Larouche and Schuett (2016) study joint participation in SSOs as an instance of repeat interaction, which dissuades opportunistic conduct. Data on joint participation in 3GPP, as measured by membership, attendance, or contributions, may be used to investigate whether repeat interaction in SSOs reduces the risk of litigation and facilitates licensing negotiations or other commercial relationships based on trust.

In addition, researchers and policy makers may investigate the effect of participating in SSOs on firms' competitive conduct. In particular, a significant source of concern about SSOs is that product market competitors may use joint participation in standardization to coordinate or enforce product market collusion. Researchers may use data on 3GPP meeting attendance in conjunction with data on discovered cartels or measures of product market competition to test whether legitimate technological coordination through SSOs may facilitate illicit collusion.

8. Conclusion

This paper unpacks the working of 3GPP - a partnership of seven SSOs that is tasked to define and maintain 3G and 4G wireless cellular standards that are widely deployed world-wide today. Based on the understanding of the institutional set-up of 3GPP's organization, rules, and procedures, this paper describes in detail a comprehensive, standardized, and readily usable dataset covering various aspects of 3GPP, including membership records, attendance records, contributions, change requests, and technical specifications.

The institutional description of 3GPP demonstrates the complexity of 3G and 4G standards. Each generation of the technology encompasses various releases that correspond with major additional features and improved functionality, built over a period of fifteen years and continuing. Each release encompasses hundreds of technical specifications based on thousands of technical contributions submitted by member firms. The description of the procedures also demonstrates the open and transparent process for selecting technical contributions based on technical merit and subject to consensus or majority vote.

The data reveals some important conclusions for 3GPP standards. First, membership is global, representing firms from over 37 countries. Second, attendance across the various working groups varies significantly. Results consistently highlight the importance of Radio Access Network (RAN) working groups which is responsible for the highest levels of attendance and the most contributions and work-items. In other words, different aspects of the standards clearly differ in their importance to the overall community of participants. Third, attendance has been increasing over time across all working groups, with a fall in 2012 and 2013 (which may be partly attributable to delay in reporting). Fourth, there are various types of technical contributions and any study entailing contributions should ideally reflect their widely varying nature, as some are true technical solutions and others are discussion papers or liaison documents to notify working groups of each other's' developments. Additionally, the approval rate for contributions is only 27%, that is, less than one-third of the proposals make their way into the standard. Fifth, the change requests are also of various types, ranging from editorial correction to an important functional modification to a specification. Finally, the number of specifications across releases have been increasing steadily over time, with over 1000 technical specifications in the latest release of the 4G standards.

Along with the detailed description of the historical development of the wireless cellular standards, how the 3GPP standard setting works, and the various aspects of the 3GPP data, this paper also highlights some important policy questions that can be answered with the help of this dataset. For example, researchers may use this data to examine whether "ex-ante" valuation techniques are useful to assess the value of technologies that are incorporated into standards. The database on the standard setting process reveals that it is not a one-shot game. Several iterations and revisions are made over the years to technical specifications. Therefore, the standards world is not divided neatly into an ex-ante and ex-post universe. Specifications can be changed and modified over long periods of time, and even made obsolete at times. As another example, the database may place claims that there are "too many" SEPs for 3G and 4G standards into the context of the scale and scope of the standard setting process. The data demonstrates that there are thousands of large technical specifications forming these standards, each containing hundreds and thousands of complex technical elements. In addition, from the technical focus of the working groups, and the amount of time and effort spent across them, it is likely clear that all technologies are not equal in their value.

The data collection and analysis of 3GPP contributions, CRs, and their outcomes from the working group meeting reports has been possible due to a deep institutional understanding of the standard setting process. The initial findings only provide some indications into potential workings and dynamics of the various participants in the value chain of standard setting. Several more questions can be asked and several more proposed theories about standard setting can be empirically tested using such data. Researchers working on

standard setting and deriving policy implications should carefully consider the institutional background and empirical proof in order to make sound policy recommendations.

References

N. Aggarwal, Q. Dai, and E. Walden. The more the merrier? How the number of partners in a standard-setting initiative affects shareholders' risk and return. MIS Quarterly, 35 (2):445-462, June 2011.

T. Bar and A. Leiponen. Committee composition and networking in standard setting: The case of wireless telecommunications. Journal of Economics and Management Strategy, 23(1):1-23, Spring 2014.

J. Baron, K. Gupta, and D. Spulber. Technology standards in the knowledge production function - Evidence from 3GPP. mimeo, 2015.

J. Baron, Y. Meniere, and T. Pohlmann. Standards, Consortia and Innovation. International Journal of Industrial Organization, 36: 22-35, 2014.

J. Baron and T. Pohlmann. Mapping Standards to Patents using Databases of Declared Standard-Essential Patents and Systems of Technological Classification, Journal of Economics and Management Strategy, this issue, 2018

J. Baron and D. Spulber. Technology Standards and Standard Setting Organizations: Introduction to the Searle Center Database, Journal of Economics and Management Strategy, this issue, 2018

R. Bekkers. Mobile Telecommunications Standards: Gsm, Umts, Tetra, and Ermes. Artech House, Boston, 2001.

R. Bekkers, R. Bongard, and A. Nuvolari. An empirical study on the determinants of essential patent claims in compatibility standards. Research Policy 40(7): 1001-1015, 2011.

R. Bekkers and B. Kang. Just-in-time inventions and the development of standards: How firms use opportunistic strategies to obtain Standard-Essential Patents (SEPs). Research Policy, 44: 1948-1961, 2015.

Bekkers, R., & West, J. (2009). The limits to IPR standardization policies as evidenced by strategic patenting in UMTS. Telecommunications Policy, 33(1), 80-97.;

A. Bonatti and H. Rantakari. The Politics of Compromise. American Economic Review, 106(2): 229-259. 2016

S. Besen and L. Johnson. Compatibility standards, competition, and innovation in the broadcasting industry. Research report, RAND Corporation, 1986.

J. Bezerra, W. Bock, F. Candelon, S. Chai, E. Choi, J. Corwin, S. DiGrande, R. Gulshan, D. Michael, and A. Varas. The Mobile Revolution: How Mobile Technologies Drive a Trillion-Dollar Impact, Boston Consulting Group (January 15, 2015), at pg. 28, available at

https://www.bcgperspectives.com/content/articles/telecommunications_technology_business_transformation_mobile_revolution/

K. Blind. An economic analysis of standards competition - the example of the ISO ODF and OOXML standards. Telecommunications Policy, 35:373-381, 2011.

K. Blind and A. Mangelsdorf. Alliance formation of SMEs: Empirical evidence from standardization committees. IEEE Transactions on Engineering Management, 60(1):148-156, February 2013.

K. Blind and N. Thumm. Interrelation between patenting and standardization strategies: empirical evidence and policy implications. Research Policy, 33(10):1583-1598, December 2004.

P. Chappatte. Standard Setting and Patent Pools-Their implications for EU Competition Law. IBC Intellectual Property and Competition Law, Brussels, 2006.

B. Chiao, J. Lerner, and J. Tirole. The rules of standard-setting organizations: an empirical analysis. RAND Journal of Economics, 382(4):905-930, Winter 2007.

M. Cohen-Meidan. The effects of standardization processes on competition: An event study of the standardization process in the us cable modem market. Telecommunications Policy, 31:619-631, 2007.

P. David. Clio and the Economics of QWERTY. American Economic Review, Papers and Proceedings, 75(2): 332-337, May 1985

B. DeLacey, K. Herman, D. Kiron, and J. Lerner. Strategic behavior in standard-setting organizations. NOM Working Paper No. 903214, Harvard Business School, 2006.

H. Delcamp and A. Leiponen. Innovating standards through informal consortia: The case of wireless telecommunications, International Journal of Industrial Organization, 36: 36-47, 2014.J. Farrell, J. Hayes, C. Shapiro and T. Sullivan.. Standard setting, patents, and hold-up. Antitrust Law Journal, 603-670, 2007.

J. Farrell and C. Shapiro. Standard setting in high-definition television. Brookings Papers on Economic Activity. Microeconomics, pages 1-93, 1992.

J. Farrell and T. Simcoe. Choosing the rules for consensus standardization. RAND Journal of Economics, 43(2):235-252, Summer 2012.

Federal Trade Commission. *The evolving IP marketplace: Aligning patent notice and remedies with competition*, A Report of the Federal Trade Commission, 2011.

L. Fleming and D. Waguespack. Scanning the commons? Evidence on the benefits to startups participating in open standards development. Management Science, 55(2):210-223, February 2009.

N. Gandal, N. Gantman, and D. Genesove. Intellectual property and standardization committee participation in the us modem industry. CEPR Discussion Paper No. 4658, Centre for Economic Policy Research, Oct. 2004.

K. Gupta. The patent policy debate in the high-tech world. Journal of Competition Law and Economics, 9(4):827-858, December 2013.

K. Gupta. Technology Standards and Competition in the Mobile Wireless Industry. Geo. Mason L. Rev., 22, 865-1021, 2015

K. Gupta and M. Snyder. Smart phone litigation and standard essential patents. Hoover IP2 Working Paper Series No. 14006, Hoover Institution Stanford University, 2014.

B. Hall, , A. Jaffe, and M. Trajtenberg. Market value and patent citations. RAND Journal of Economics, 36(1): 16-38, 2005

B. Kang and K. Motohashi. Essential intellectual property rights and inventors' involvement in standardization. Research Policy, 44(2):483-492, March 2015.

K. Kuhn, F. Scott-Morton, and H. Shelanski. Standard setting organizations can help solve the essential patents licensing problem, Competition Policy International Antitrust Chronicle (3) 2013.

P. Larouche and F. Schütt. Repeated Interaction in Standard Setting. TILEC Discussion Paper, 2016-010, 2016.W. Lehr. Compatibility standards and industry competition: Two case studies. Economics of Innovation and New Technology, 4(2):97-112, 1996.

A. Leiponen. Competing through cooperation: Standard-setting in wireless telecommunications. Management Science, 54(11):1904-1919, November 2008.

M. Lemley. Intellectual Property Rights and Standard-Setting Organizations. California Law Review, 90(6): 1889-1980, 2002.

M. Lemley. Ten things to do about patent holdup of standards (and one not to). BCL Rev. 48:149, 2007.

M. Lemley and C.Shapiro. Patent holdup and royalty stacking. Texas Law Review 85: 2163, 2006.

J. Lerner and J. Tirole. A model of forum shopping. American Economic Review, 96(4): 1091-1113, September 2006.

J. Lerner and J. Tirole. Standard-essential patents. Journal of Political Economy, 123(3): 547-586, 2015.

R. Ranganathan and L. Rosenkopf. Do ties really bind? the effect of knowledge and commercialization networks on opposition to standards. Academy of Management Journal, 57(2):515-540, 2014.

L. Rosenkopf, A. Metiu, and V. George. From the bottom up? Technical committee activity and alliance formation. Administrative Science Quarterly, 46(4):748-772, 2001.

M. Rysman and T. Simcoe. Patents and the performance of voluntary standard-setting organizations. Management Science, 54(11):1920-1934, November 2008.

C. Shapiro. Navigating the patent thicket: Cross licenses, patent pools, and standard setting. Innovation Policy and the Economy, Volume 1. MIT press: 119-150, 2001.

T. Simcoe. Standard setting committees: Consensus governance for shared technology platforms. American Economic Review, 102(1):305-336, February 2012.

D. Spulber. Unlocking Technology: Antitrust and Innovation. Journal of Competition Law and Economics, May 2008.

D. Spulber. Standard Setting Organizations and Standard Essential Patents: Voting Power versus Market Power. Working Paper, 2016

D. Swanson and W. Baumol. Reasonable and nondiscriminatory (RAND) royalties, standards selection, and control of market power. Antitrust Law Journal 73(1), 2005.

P. Wakke and K. Blind. The impact of participation within formal standardization on firm performance. mimeo, April 2012.

M. Weiss and M. Sirbu. Technological choice in voluntary standards committees: An empirical analysis. Economics of Innovation and New Technology, 1(1-2):111-133, 1990.

W. Wen, C. Forman, and S. Jarvenpaa. Standards as a knowledge source for R&D: A first look at their incidence and impacts based on the inventor survey and patent bibliographic data. Discussion Paper No. 11018, Research Institute of Economy, Trade and Industry (RIETI), 2014.

Appendix A: Database Outline & Table Descriptions

SCDB_3GPP_attendance				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
meeting_id	Meeting ID	102,183	946	SCDB_3GPP_meetings
company-name-normalized	Normalized company name	102,201	528	SCDB_company_id
attended	Attended yes or no	102,189	2	
individual role	e.g. attendee, chair, observer	102,188	19	

SCDB_3GPP_meetings				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
meeting_id	Meeting ID	943	943	SCDB_3GPP_attendance SCDB_3GPP_contributions SCDB_3GPP_changerequests
meeting_title	Meeting title	943	942	
workinggroup_id	Working group ID	943	23	
tsg_id	Technical specification group ID	943	3	
city	City	943	173	
meetingstartdate	Meeting start date	943	398	
meetingenddate	Meeting end date	943	385	

SCDB_3GPP_workitem				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
work-item_id	work item ID	3,060	3,060	
tdoc_number	Technical document number	3,239	3,176	SCDB_3GPP_contributions
workitemtitle	Work item title	2,852	2,239	
newspec-created	New spec created ID	1,113	746	
affected-specs	Affected specification ID(s)	2,071	1,181	
tsg-id	Technical specification group ID	2,837	4	SCDB_3GPP_contributions SCDB_3GPP_attendance SCDB_3GPP_meetings

SCDB_3GPP_workitem_supporting_entity				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
wid	3GPP WID (Work item ID)	15,301	2,263	SCDB_3GPP_workitem_to_spec
raw_company	Raw company name	15,301	391	
company-name	Normalized company name	15,301	370	SCDB_3GPP_attendance SCDB_3GPP_change_request_authorship SCDB_3GPP_work-items_supporting_companies
parent-company-name	Firm rolled up to the parent company level	15,301	325	SCDB_3GPP_attendance SCDB_3GPP_change_request_authorship SCDB_3GPP_work-items_supporting_companies

SCDB_3GPP_workitem_to_spec				
Variable Name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
spec	3GPP specification number	16,936	108	3GPP_spec_docidn
release	Release number/year	16,936	13	3GPP_spec_docidn
Uniqueid	3GPP UID (Unique ID)	16,936	3,148	
wid	3GPP WID (Work item ID)	13,387	1,563	SCDB_3GPP_workitem SCDB_3GPP_workitem_supporting_entity
date	Date (MM/DD/YYYY)	16,355	158	

SCDB_3GPP_contributions				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
tdoc_number	Technical document number	301,466	301,336	SCDB_3GPP_workitem
tsg	Technical Specification Group	301,348	4	
workinggroup	Working Group	301,316	14	
meeting_id	Meeting ID	301,024	602	SCDB_3GPP_meetings
document_type	Document Type	283,397	6	
revised_document_type	Revised document type	283,397	8	
raw_document_type	Raw document type	300,933	544	
raw_document_title	Raw document title	301,363	164,479	
decision	Decision	301,316	6	

SCDB_3GPP_contribution authorship				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
tdoc_number	tdoc-number	396,285	282,960	SCDB_3GPP_contributions
company_name	Normalized firm name	396,273	342	SCDB_3GPP_attendance SCDB_3GPP_change_request_authorship SCDB_3GPP_workitems_ supporting_companies

SCDB_3GPP_changerequests				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
cr_id	Change request ID	146,368	146,368	
tdoc_nr_1stlevel	Plenary meeting document number for the change request	146,368	25,286	SCDB_3GPP_contributions
tdoc_nr_2ndlevel[59]	Working group document number for the change request	146,368	138,696	
spec	Technical Specification ID that the change request relates to	146,368	1,228	SCDB_3GPP_workitem_to_spec SCDB_3GPP_spec_docidn
release	Standards release of the Technical Specification	146,368	17	
crtype	Change request type definition	141,853	6	
workinggroup	ID of the specific 3GPP Working Group (WG)	146,368	23	SCDB_3GPP_contributions SCDB_3GPP_attendance SCDB_3GPP_meetings
tsg	Technical specification group ID	146,368	4	SCDB_3GPP_contributions SCDB_3GPP_attendance SCDB_3GPP_meetings

[59] A change request is normally submitted for discussion to the Working Group (WG) responsible for the specification. Once the WG has agreed that the Change Request is both valid and required (often it may be revised several times before reaching this stage), it is presented, on behalf of the WG (rather than the originating member organization) as an agreed proposal to the parent TSG plenary for final approval. If the document was presented directly at plenary meeting, both 1st level and 2nd level document numbers will be the plenary document number.

SCDB_3GPP_cr_authorship				
Variable name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
cr_id	Change request ID	273,309	146,368	SCDB_3GPP_changerequests
company_name_raw	Raw company name	273,309	2,314	SCDB_3GPP_attendance SCDB_3GPP_change_request_authorship SCDB_3GPP_work-items_supporting_companies
company_name	Normalized firm name	273,309	290	SCDB_3GPP_attendance SCDB_3GPP_change_request_authorship SCDB_3GPP_work-items_supporting_companies
source_level	First/Second level	273,309	2	

SCDB_3GPP_spec_docidn				
Variable Name	**Description**	**Number obs.**	**Unique obs.**	**Connects with**
spec	3GPP specification number	11,336	1,087	
version	Version number	17,611	418	
release	Release number/year	17,611	14	
document_id	Standard document id	17,611	1,087	
doc_idn	SCDB unique standard document id	17,611	17,611	**SCDB_standards**